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E. M. BURAS, JR., ET AL

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LINE-OPERATED VACUUM TUBE VOLTMETER

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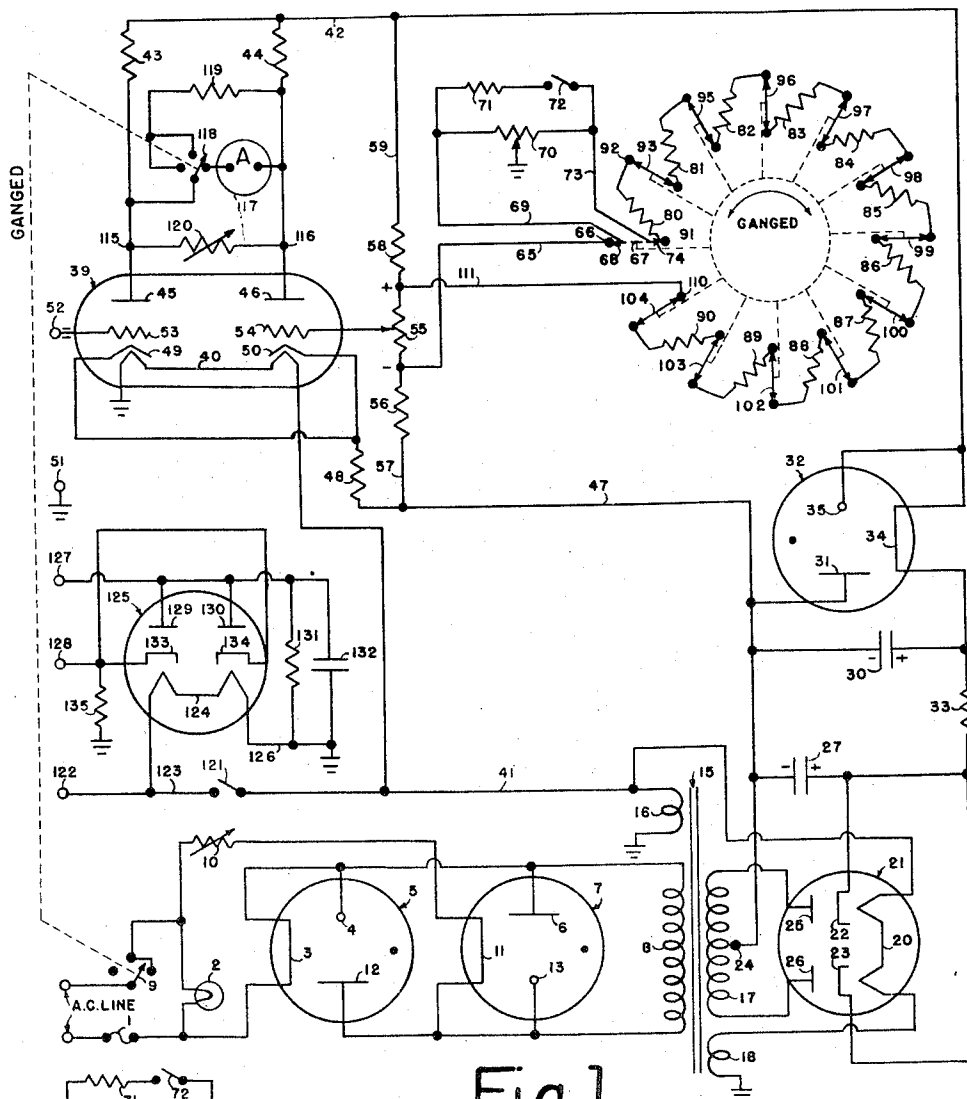


Fig. 1

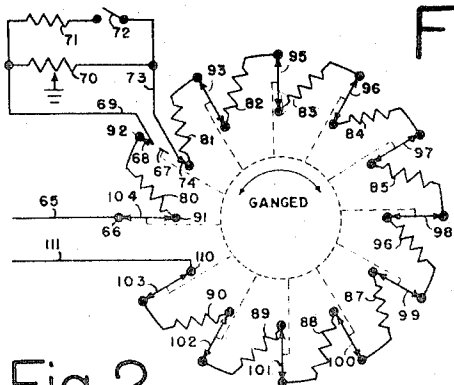


Fig. 2

INVENTORS

Edmund M. Buras, Jr.
J. David Reid

UNITED STATES PATENT OFFICE

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LINE-OPERATED VACUUM TUBE
VOLTMETER

Edmund M. Buras, Jr., and John David Reid,
New Orleans, La., assignors to the United
States of America as represented by the Secre-
tary of Agriculture

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1

This application is made under the act of March 3, 1883, as amended by the act of April 30, 1928, and the invention herein described, if patented, may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment to us of any royalty thereon.

This invention relates to voltmeters, and in particular to line-operated low uni-directional meters for measuring voltage involved in oxidation-reduction titrations, precipitation titrations, and pH determinations.

The objects of the invention are to provide a laboratory voltmeter having high sensitivity, good stability, negligible grid current, accuracy, and one which is operated directly from an alternating current line, gives continuous indication, is simple in construction and operation, is portable, has variable sensitivity, has wide range of operation, and which is of low cost.

For a particular description of the invention, reference is made to the accompanying drawing, in which

Figure 1 shows a wiring diagram of the instrument; and

Figure 2 is a detail showing a setting of one of the controls.

In the drawing, a voltage supply and regulating circuit which renders a stabilized voltage to the power transformer will first be described. Terminals are provided for connecting to the alternating current line indicated in the drawing as "A. C. line," conductors being provided for connecting the terminals to the primary of the power transformer. One conductor is connected through a protective fuse 1 to one terminal of the pilot bulb 2, thence through jumper 3 to the anode 4 of one gaseous discharge voltage-regulator tube 5, thence to the cathode 6 of a second gaseous discharge voltage-regulator tube 7, and thence to one end of the primary 8 of the power transformer. The other conductor is connected through two contacts of a three-position switch 9 to the second terminal of the pilot bulb 2, thence through a variable resistance 10, thence through jumper 11 to the cathode 12 of the first gaseous discharge voltage-regulator tube 5 and to the anode 13 of the second gaseous discharge voltage-regulator tube 7, and thence to the other end of the primary 8 of the power transformer. Thus, the pair of voltage-regulator tubes 5 and 7 are reversely connected across the conductors connecting the terminals to the primary of the power transformer. These tubes are No. 874 or tubes of similar characteristics.

2

In operation, any increase in line voltage causes a sharp increase in current through the gaseous discharge voltage-regulator tubes, with a corresponding increase in potential drop across resistor 10. The net effective increase in voltage applied to the primary of the power transformer is a small fraction of the increase in the A. C. line itself. For decreases in line voltages, all effects are reversed. When resistor 10 is properly adjusted so that the gaseous discharge regulator tubes remain just glowing at the lowest excursions of the line voltage, the primary of the power transformer will be effectively maintained at approximately 90 volts while the line voltage may vary over a range from about 110 to 125 volts.

The voltage supply circuits are obtained from the power transformer 15 which is provided with secondaries 16, 17 and 18. Secondaries 16 and 18 which supply an A. C. potential of approximately 4.7 and 1.8 volts, respectively, for heater voltage supply are each connected at one end to ground. The ungrounded terminals of secondaries 16 and 18 are connected to the terminals of heater 20 of a double diode vacuum tube rectifier 21, this tube being No. 7A6 or a tube of similar characteristics. The phase relation between the free ends of secondaries 16 and 18 is such that the voltages from the winding are additive to give approximately 6.5 volts. This heats the cathodes 22 and 23 of the rectifier tube to the appropriate temperature.

The vacuum tube rectifier is connected to the secondary 17 of the power transformer which supplies approximately 175 volts on each side of a center-tap 24, the outer ends of this secondary being connected to the plates 25 and 26 of the rectifier tube. Center-tap 24 is connected through a conductor to one plate of a filter condenser 27, the other plate of which is connected through a conductor to both cathodes 22 and 23, with the result that a rectified direct current voltage of approximately 175 volts is applied to the filter condenser.

Any double diode vacuum tube rectifier, or a pair of single diode rectifier tubes, can be utilized in place of the 7A6 suggested, provided that they have proper characteristics. The 7A6 type is chosen because its heater power consumption is low and its diodes are suited for the rectification of approximately 14 milliamperes, the current required to operate the remaining portion of the instrument. The filter condenser 27 may have any of a variety of voltages and capacity ratings, so long as it gives sufficient filtering. Ratings of 16 microfarads and 450 volts are convenient.

A conductor connects the negative plate of con-

3

denser 27 to the negative plate of a second condenser 30 similar to condenser 27, thence to the cathode 31 of a gaseous discharge voltage-regulator tube 32, which may be an OD3 or tube of similar characteristics. A conductor also connects the positive plate of condenser 27 through a limiting resistor 33 to the positive plate of condenser 30, thence through jumper 34 to the anode 35 of tube 32. The voltage regulating characteristic of tube 32 is utilized to maintain a constant voltage across the amplifier and the biasing circuits later described.

Tube 39 is a twin-triode amplifier (No. 6F8-g) and operates as a first and second triode. The heater filaments 40 of the triodes are heated directly through conductor 41 and the ground from the 4.7 volt secondary 16 of the power transformer. This operates the filaments at a reduced temperature with corresponding reduced electronic emission, giving more stable operation throughout the life of the tube. Constant plate voltage is fed from the positive terminal of regulator tube 32 or power supply through conductor 42 and first and second plate resistors 43 and 44, respectively, to the plates 45 and 46, of the first and second triodes, and from the negative terminal of the regulator tube or power supply through conductor 47 and cathode resistor 48 to cathodes 49 and 50 of both triodes. The input, or voltage to be measured, is connected to accessible terminals 51 and 52, terminal 51 being grounded and terminal 52 being connected through a shielded lead to grid 53 of the first triode, thus to provide means for applying the input (relative to the ground) to the grid 53, but not to grid 54, and to swing grid 53 in accordance with the input.

Resistor 48, of resistance value in the order of magnitude or greater than the plate resistances of the triodes, has a degenerative effect on any change in the plate current through plate 45, and thus confers stability to operation of the triode to the grid of which the voltage to be measured is applied, even though the potential applied to the plate circuits of the triodes may vary somewhat. This effect is obtained, however, without loss in sensitivity, because both cathodes 49 and 50, being connected together, have the same operating potential, and any degenerating potential produced by change of current through resistor 48 is applied to both cathodes. The degenerating effect of the resistor is therefore in the same direction in both triodes, so that change in current through the plates has substantially no effect on the indicating meter 117, later described.

Since it is the aim of this instrument to be conveniently operable with the input grid 53 at the "floating" or free-grid potential, a means is also provided for varying the bias of grid 54 while grid 53 is left "floating" or free to assume the free-grid potential. Adjustable constant grid bias is applied to grid 54 through a first adjustable voltage divider 55, one terminal of which is connected through resistor 56 and conductor 57 to the negative terminal of regulator tube 32, and the other terminal of which is connected through resistor 58 and conductor 59 to the positive terminal of the tube. While changes in bias on grid 54 result in changes of potential of cathodes 49 and 50 relative to ground, grid 53 remains at the free-grid potential throughout adjustment of voltage divider 55, since grid 53 is not connected to the input voltage while adjustments are made.

4

Means is also provided to vary the bias of grid 53 to be effective when the conducting input or voltage to be measured is connected to terminals 51 and 52. For this purpose a second adjustable voltage divider arrangement is provided in parallel circuit to voltage divider 55 through conductor 65 leading from the negative end of divider 55 to one fixed contact 66 of a double movable and double fixed contact switch 67, thence through movable contact 68 and conductor 69 to one end of second adjustable voltage divider 70, the movable contact of which is connected to ground. A resistor 71 is connected through a switch 72 in parallel with voltage divider 70 and the other end of the voltage divider is connected through conductor 73 to the other movable contact 74 of the switch 67. Divider 70 provides for effecting a continuous change of bias on grid 53 within the range of the divider.

In operation, with a conducting input applied between terminals 51 and 52, one setting of the movable contact of divider 70 will bring meter 117 (later described) to an arbitrary scale reading, of say zero. Deviations of input voltage from this value cause proportional deviations in the plate current of both triodes. If a connector free of potential source is connected between terminals 51 and 52, the reference point on the movable contact will correspond to zero potential. All other positions of the movable contact may be evaluated in terms of input.

A switching arrangement is also provided for selectively throwing resistors in series with divider 70 from one side of the divider to the other without changing the overall series resistance, thus to provide a step-by-step change of the bias on grid 54. This is accomplished by providing a set of resistors numbered in the diagram as 80 to 90, inclusive. Resistor 80 is connected at one end to fixed contact 91 of switch 67 and at the other end to fixed contact 92 of a double fixed-contact, single movable contact switch 93 adjacent to switch 67. Resistors 81 to 90 are similarly connected through adjacent switches 95 to 104, inclusive, fixed contact 110 of the last switch 104 being connected through conductor 111 to the positive end of voltage divider 55. Switches 67, 93 and 95 through 104 are ganged and so arranged that as the contacts 68 and 74 of switch 67 are advanced (clockwise as illustrated in the drawing) to the positions of switch 93, all movable contacts of the other switches are likewise advanced a corresponding amount. A suitable switching arrangement for the purpose is a 12-position, meter insertion type switch.

With the switches in position as shown in the diagram of Figure 1, electronic flow from conductor 65 passes through voltage divider 70 (also through resistor 71 if the switch 72 is closed), thence through conductor 73 and through resistors 80 through 90 in series, and thence through conductor 111 to the positive side of voltage divider 55. If, however, the switches are advanced one position to the position as shown in Figure 2, for example, electronic flow from conductor 65 will pass first through resistor 80, then through voltage divider 70, and then through resistors 81 through 90 in series and conductor 111. In a similar manner, the movable contacts may be advanced to ten other positions to place any desired number of the resistors 80 through 90 on either side of the divider 70, the remaining resistors being on the other side, thus selectively to throw some or all of the resistors from one side of the voltage divider to

5

6

the other. Although any number of resistors corresponding to those shown as 80 through 90 may be used, the number chosen is convenient for the purpose of the present instrument.

Any swing in potential of grid 53 relative to grid 54 will result in a corresponding change in current from plate 45 relative to current from plate 46. This will cause a relative shift in potential between points 115 and 116 in the plate circuits which will be registered on a meter 117 connected across these points. The meter is connected through a three-pole switch 118 similar to switch 9 and ganged thereto. Switches 9 and 118 when set in the extreme clockwise position as shown in the diagram throw both the electronic circuit and the meter in operation. It is sometimes desirable while making adjustments with the electronic circuit thrown in to protect the meter. This is accomplished by setting switches 9 and 118 in the center tap position, in which case the electronic circuits are yet in operation, but the meter is thrown out of circuit and a resistor 119 having a resistance equivalent to that of the meter is thrown in circuit in place of the meter. On the open position of switch 9, resistor 119 remains in circuit, which is of course immaterial.

Sensitivity of the meter is controlled by a variable resistor 120 in parallel with the meter, which for optimal conditions should have a maximum resistance value about three times that of the meter and be adjustable over the whole range from zero to its maximum.

It is desirable that all components be enclosed in a metal shield effectively grounded so that presence of the operator and interfering disturbances may have no adverse effect on operation of the instrument.

Although variation may be made in ratings of the resistors, the following are suggested with tubes of the type indicated: resistor 10, 200 ohms, 25 watts; resistor 33, 10,000 ohms, 1 watt; resistors 43, 44, 48, 56 and 58, each 25,000 ohms, 5 watts; resistance of voltage dividers 55 and 70 each, 10,000 ohms, 2 watts; resistor 71, 600 ohms, 0.5 watt; and resistors 80 through 90 each 25 ohms, 0.5 watt.

In operation, prior to any use of the instrument and with no connection made to the input terminals, voltage divider 55 should be manipulated so that the indication of the meter 117 is reduced to zero.

To use the instrument as a titrimer, such as in acid-base, precipitation, or oxidation-reduction titrations, the cell or pair of electrodes is connected to the input terminals 51 and 52. By means of the voltage divider 70 and associated resistors, the indication of the meter 117 can be brought to any point on the scale which is convenient. This is preferably done with switch 72 in closed position, but if the necessary adjustment cannot be accomplished with the switch in this position, it may be opened. Sensitivity of the meter is controlled by variable resistor 120, which may be adjusted to any value from zero to maximum, according to the needs of the determination.

If it is desired to determine accurate values of the acidity of the solution expressed as a pH, it is necessary first to calibrate two points of the scale of meter 117, thereby allowing the calculation of the corresponding values of pH for all other points on the scale, taking advantage of the linearity of the instrument.

The calibration can be accomplished in two procedures:

First, buffered solutions may be used for calibration. In this case, the glass-electrode-calomel cell, or other pH responsive cell, is connected to the input terminals. The cell is immersed in a buffered solution of greater acidity than the value to be measured. The meter is then adjusted to indicate zero by means of the voltage divider 70 while sensitivity is adjusted to maximum by means of variable resistor 120. The electrodes are then washed and immersed in a solution of greater alkalinity than the value to be measured. The meter is then adjusted to the full scale deflection by reduction of the sensitivity. The electrodes are then washed and immersed in the solution of unknown acidity. The meter will be deflected to some point intermediate on the scale, and the corresponding pH of the unknown may be calculated by interpolation. If the buffered solutions available are of such acidity as to make interpolation cumbersome, it is possible, by judicious use of the range and sensitivity controls, to adjust the meter at two points on the scale other than zero and maximum, thereby simplifying subsequent readings.

Second, the stepwise potential shifts due to the selective placing of resistors 80 through 90 on each side of voltage divider 70 may be used.

Before calibration by this second procedure can be effected, it is necessary that two preliminary operations be performed. One operation involves determination of the pH of a solution which causes the particular glass-electrode-calomel cell combination to provide zero potential across the meter 117. The other operation involves determination, by comparison with a calibrated potentiometer, the potential shifts supplied by the stepwise insertion of resistors 80 through 90 to opposite sides of divider 70. This latter operation is accomplished by short circuiting the input terminals and adjusting meter 117 to zero and then moving ganged switches 67, 93 and 90 through 104 one step and observing the deflection resulting on the meter. The ganged switches are then returned to the initial position, and a known potential obtained from a calibrated potentiometer is substituted for the connector across the input terminals. If the same deflection of the meter is obtained, the potential shift supplied by the one-step shift of the ganged switches is equal to the potential supplied by the calibrated potentiometer. Knowing the pH value of the cell for zero E. M. F., the value of each stepwise shift of the potential supplied by shifting of the ganged switches, and the relationship between the potential of the cell and the acidity of the solution in which it is immersed, it is a simple matter to derive the corresponding pH value for each point of setting of the ganged switches. This done, the various stepwise settings of the ganged switches can be used to calibrate the scale of the meter in exactly the same manner as were the standard buffered solutions in the first procedure described above, except that a connector is used between the input terminals instead of the glass-electrode-calomel cell. Once the preliminary operations are accomplished, they need be repeated only infrequently, so that if many pH determinations are to be made and only fair accuracy is desirable, the second procedure is ultimately more economical of time than the first procedure, which requires the standard buffered solutions.

75 Use of the instrument as a voltmeter is much

the same as its use as a titrimeter or pH meter, except that it is usually desired to have zero volts of the voltage to be measured read at one end of the scale of meter 117. This is accomplished by short circuiting the input terminals and adjusting the meter to zero with the voltage divider 70. A source of standardizing potential is then applied to the input terminals and the meter is adjusted to full scale or to any desirable point on the scale by means of the sensitivity control. Thus calibrated, the meter will indicate both the magnitude and the polarity of any D. C. voltage, or if used with a pulsating current, the mean value of the pulsating current applied to the input terminals.

An auxiliary portion of the device is shown in Figure 1, represented by numbers 121 to 135. This portion is used in combination with the rest of the device for conductometric titrations to supplement the potentiometric titrations done with the other portion thereof. For this purpose, switch 121 is closed, thus connecting terminal 122 to the source of current through conductors 41 and 123, and terminal 127 is connected by an outside jumper to terminal 52. Heaters 124 of the tube are connected to conductor 123 and through conductor 126 to the ground. Terminal 127 is connected to plates 129 and 130 and through resistor 131 and condenser 132 to conductor 126. Terminal 128 which leads to cathodes 133 and 134 is connected through resistor 135 to the ground.

The tube may be a 7A6 or other tube of similar characteristics. Although variations may be made in rating of the resistors, the following are suggested with tubes of the type indicated: resistor 131, 1 megohm, 0.5 watt; resistor 135, 2 ohms, 10 watts.

To use the instrument for conductometric titrations, such as in the acid-base titrations or precipitation titrations (switch 121 being closed and terminal 127 connected to terminal 52), the cell containing two electrodes, for example platinum plates, is connected to the terminals 122 and 128. Terminal 51 is not used. During titration, changes of conductance occurring in the cell affect the passage of current between the terminals 122 and 128 which in turn are reflected in the meter 117. Useful results are obtained if the readings obtained from the meter are plotted directly against the quantities of solution added for each reading. However, direct conductances are not obtained but if these are desired they may be obtained by use of a conversion factor using known cell constants.

Having thus described our invention, we claim:

1. A voltmeter comprising a first triode, a direct current power supply, a first triode plate resistor, the positive terminal of said power supply being connected to the plate of said first triode through said first triode plate resistor, a second triode, a second triode plate resistor, the positive terminal of said power supply being also connected to the plate of said second triode through said second triode plate resistor, means for connecting a meter across points in the plate circuits of said triodes, a cathode resistor, the negative terminal of said power supply being connected to the cathodes of both triodes through said cathode resistor, a first adjustable voltage divider connected across the terminals of the power supply for varying the bias of the grid of the second triode, two terminals accessible for connection to a voltage to be measured, one of said terminals being connected to the grid of the first triode, and a second adjustable voltage divider connected across the terminals of said power supply for varying the voltage to said other accessible terminal, thereby to apply an adjustable voltage to the grid of the first triode in addition to the voltage being measured.

2. The voltmeter as defined in claim 1 characterized in that a plurality of resistors are provided in series with the second voltage divider, and a switching arrangement is provided for selectively throwing some or all of the resistors from one side of the second voltage divider to the other side thereby to give a step-by-step change in the voltage in addition to the continuous change in voltage applied to said other accessible terminal.

EDMUND M. BURAS, JR.
JOHN DAVID REID.

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