CENTRAL SCIENTIFIC COMPANY

OPERATING INSTRUCTIONS

Two-Meter Potentiometer Slidewire Bridge
No. 83406

1. Purpose

The two-meter potentiometer slidewire bridge is a device for measuring the emf (electromotive force) of an electrical cell or a DC circuit. The device is well suited for use in elementary experiments on DC electricity.

2. Theory

The potential difference which a battery or one of its cells can maintain between its terminals decreases as the current supplied by the battery or cell increases. Its maximum potential difference or electromotive force is, therefore, attained only with zero current output; in other words, when the cell is on open circuit. This does not mean that the cell in operation is less active but rather that a portion of the released energy is then internally dissipated.

The electromotive force of a cell is the energy which this source can supply per unit of electrical charge. The potential difference between two points in an electrical circuit is a measure of the work done per unit charge in transmitting electrical charge from the one point to the other. The practical unit of both electromotive force and potential difference is the volt, which is one joule of energy per coulomb of charge. Since the energy supplied by the cell must equal the energy dissipated in the circuit, the electromotive force **E** may be set equal to the sum of the potential differences for the entire circuit, both that inside the cell **v** and in the external circuit **V**. Thus

$$E = V + v \qquad (1)$$

The terminal voltage of the cell is then

$$V = E - v = E - Ir \qquad (2)$$

where **I** is the current in the cell and **r** is the internal resistance of the cell. Since all cells have internal resistance, this expression states that the voltage between the terminals of the cell is a maximum and equal to **E** only when the current **I** is zero.

Voltages are usually measured with a voltmeter and it might, therefore, be assumed that a voltmeter requires current for its operation and as a result the terminal potential difference, called terminal voltage, is reduced when the voltmeter is connected to the cell. The reading would, therefore, be less than the electromotive force.

A useful and accurate device for measuring potential differences, including electromotive forces, is the slidewire potentiometer shown diagrammatically in Figure 1.

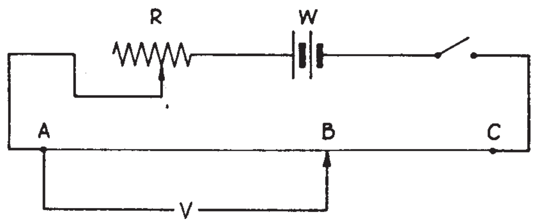

Figure 1 Simple slide-wire potentiometer

This instrument is designed to read voltages by a comparison method which does not require current in the measured circuit. Thus the necessary condition for measuring electromotive forces is secured, namely that the cell furnish no current. The essential feature of the potentiometer is a uniform wire **AC** of relatively high resistance, Figure 1, with a working battery **W** attached to the ends of this wire to produce a uniform fall of potential along its length.

A fixed contact at **A** and a movable slide contact at **B** permit selecting any voltage from zero when **B** and **A** coincide, to the maximum value across **AC** when **A** and **B** have their maximum separation.

If a given length of this wire L_{AB} millimeters (see Figure 1) has a drop of V_{AB} volts, the drop in volts per millimeter length of wire will be given by $[V_{AB} / L_{AB}]$. Then any arbitrary span of wire L_x millimeters in length will have a potential difference $V_x = [V_{AB} / L_{AB}] L_x$ volts. The value of $[V_{AB} / L_{AB}]$ must be known; that is, the wire must be calibrated before it can be used to determine V_x.

Calibration of the Potentiometer: To calibrate the wire, a galvanometer **G** and a cell E_s of known electromotive force (called a standard cell) are connected into the circuit as shown in Figure 2.

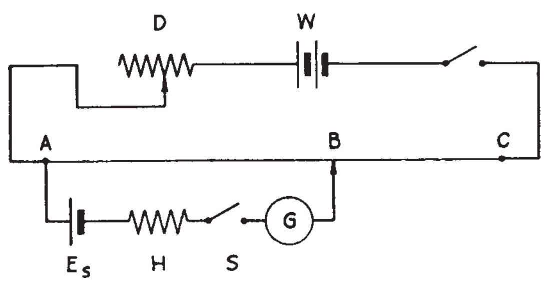

Figure 2 Calibration of the potentiometer.

If the voltage drop **A** to **C** produced by the working battery **W** is greater than the electromotive force of the standard cell E_s, there is some span of wire **AB** for which the potential drop V_{AB} is equal to the electromotive force of this cell. When the cell is connected so that its potential opposes the equal potential drop in the wire, no current will be present in the cell and the needle of the galvanometer will indicate a current. Knowing both V_{AB} and L_{AB} the value of the potential drop in volts per millimeter or centimeter length of wire may then be computed and other potential differences V_x measured.

Direct-Reading Potentiometer: The required length of wire **AB** for zero current in the galvanometer circuit may be changed by varying the resistance of the rheostat **D**. Adjusting the resistance so that a balance is obtained when the numerical value of the wire length spanned corresponds to the electromotive force of the standard cell giving, for example, one millivolt per millimeter, produces a direct-reading potentiometer. This is a very convenient and timesaving arrangement. Now an unknown or test cell $\mathbf{E_x}$, replacing $\mathbf{E_s}$, may be balanced in the circuit by shifting the slide **B** until zero galvanometer current is again attained and its terminal voltage, or electromotive force, read directly from the scale of a meter stick placed below the wire. It is evident, however, that the new balance can be obtained only if the potential of this second cell falls within the range of potential drop along the wire. This depends upon the voltage of the working battery and the calibration scale used.

Terminal Potential of Cells Supplying Energy: As stated earlier, the terminal potential of a cell attains its maximum value, or electromotive force, when the current in the circuit is zero, that is when the outside resistance in its circuit is infinitely large. Rewriting Equation (1) for a simple circuit in the form

$$E = I(R + r) \qquad (3)$$

expresses the fact that as the external resistance **R** of the circuit is decreased the current increases and the terminal voltage of the cell is lowered.

The experimental data for the following graphs were taken with a gravity cell (**E = 1.0958 volts**) supplying energy to a shunt circuit with external resistance **R**.

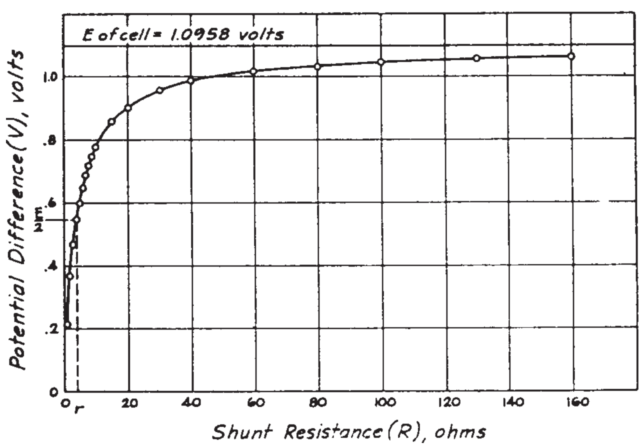

Figure 3 Potential difference versus shunt resistance for a gravity cell

Note in the graph, Figure 3, that as the external resistance was made larger, and thus the current smaller, the terminal voltage of the cell slowly approached the electromotive force in value.

Internal Resistance of a Cell: For the condition where the terminal voltage **V** is equal to **E / 2** the internal and the external potential drops must be equal, that is,

$$V = v$$

and hence

$$R = r$$

It is thus possible to read the internal resistance of the cell directly from the graph. On the graph in Figure 3, it appears that the internal resistance of the gravity cell used was about 4 ohms. The scale of this graph is made to cover such a large range of readings that it is difficult to read the resistance value at **E / 2** with any degree of accuracy. Replotting this interesting region on a larger scale in Figure 4 shows that the internal resistance of the cell was 4.13 ohms.

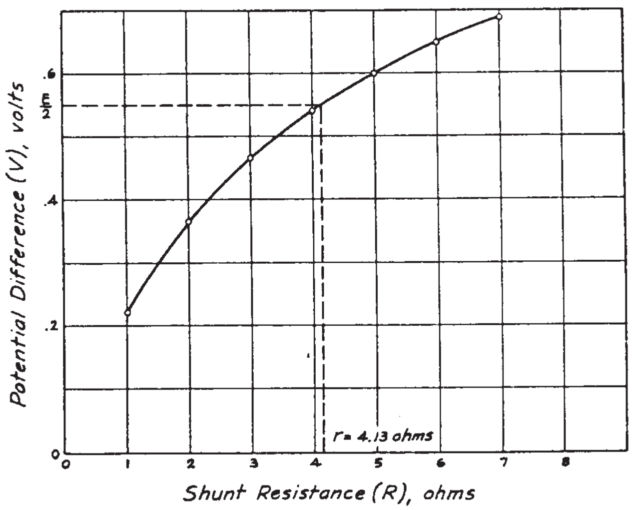

Figure 4 A portion of Figure 3 plotted on an enlarged scale.

It is possible also to compute the internal resistance of the cell, selecting particular readings, from the data used in the graph.

Since **E = I (R + r)** and **I = (V / R)** for any particular value of **R**,

$$E = (V / R) (R + r) = V + V (r / R)$$

Since all the values except **r** are experimentally known, its value may be computed. Thus with **R** set for 3 ohms in the experimental work plotted in the graphs, **V** was measured as 0.4636 volt.

$$r = (E - V) (R / V)$$

$$r = (1.0958 - 0.4636) (3 / 0.4636)$$

$$r = 4.09 \text{ ohms}$$

The variation in the values **r** as computed with data for the several individual readings may be due to variation in the cell as well as indicate in some measure the experimental accuracy of the work.

There is still a third way of obtaining the internal resistance of the cell. Plotting the data with terminal voltage as ordinate and current as abscissa gives the straight line graph of Figure 5.

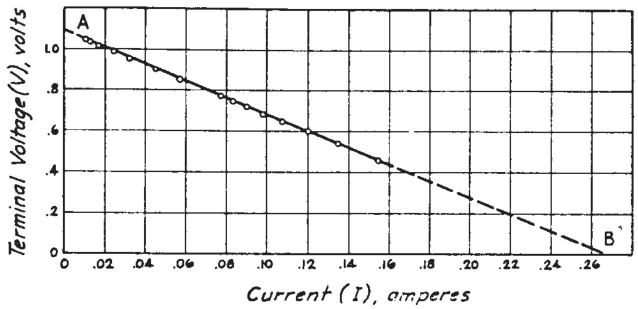

Figure 5 Terminal voltage versus current for a gravity cell

The negative of the slope of this curve is also the internal resistance of the cell. Using the extreme values of the spans,

$\Delta V = 1.09+$ volts

$\Delta I = 0.266$ ampere

Hence

$r = (1.09+ \text{ volts}) / (0.266 \text{ ampere}) = 4.10$ ohms

Thus the internal resistance of the cell so determined is 4.10 ohms.

3. Description

Two identical resistance wire, each 1m in length, are mounted on adjacent meter sticks. A heavy bus bar connects the two wires at one end, and binding posts are provided at the other end for connection to a circuit. A contact key, with binding posts, slides along either of the two wires as required.

4. Operation

4A. Adjustments

If, on receipt, the sliding contact key mounted on the instrument does not slide easily, carefully adjust the spring action of the key frame to suit the width of the meter stick or the spacing between the meter stick and the bus bar. If the key's tension spring seems to be somewhat loose, push the frame inward to narrow its width.

4B. Experimental Procedure

A convenient experimental arrangement for the calibration of the potentiometer wire and the subsequent measurements of an unknown or test cell is shown in Figure 6.

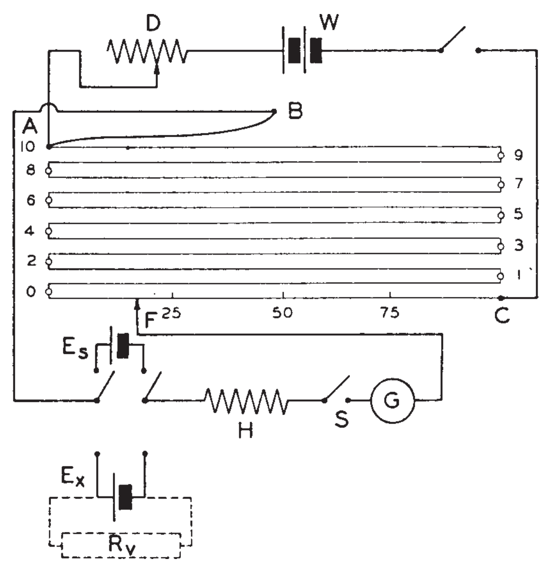

Figure 6 Calibration and use of eleven-meter slide-wire potentiometer

The potentiometer wire is composed of eleven identical one-meter lengths of resistance wire connected in series. The working battery **W** is attached to the extreme ends **AC** of this wire with a rheostat **D** in series which is sued for the calibration adjustment.

One side of the galvanometer circuit **G**, which includes the cells for calibration and for study, is fastened to the slide **F** which can move along the near or lower wire. The other end is attached to a traveling plug **B** which may be attached to the end of any one of the eleven wires. Thus any wire length span **B** to **F** from 0 to 11m is possible.

When the double-pole double-throw switch in the galvanometer circuit **G** is thrown to $\mathbf{E_s}$ the apparatus is connected for calibration. When it is thrown to the test cell $\mathbf{E_x}$ the potential difference between the terminals of the test cell may be measured. This potential difference is the electromotive force of $\mathbf{E_x}$ when the shunt resistance $\mathbf{R_v}$ is infinitely large, that is an open circuit. When $\mathbf{R_v}$ is added a study may be made of the terminal voltage change of the test cell for different values of the shunt resistance.

Calibration: Connect the ends of the eleven-meter bridge wire and rheostat **D** in series to the working battery **W** as shown in Figure 6.

With the galvanometer circuit protected by the high resistance **H** and with tap switch **S** open, connect one end of this circuit to the traveling plug **B** and the other end to the slide **F**.

Locate **B** and **F** so that they span a wire length which is numerically the same as the electromotive force of the standard cell used. This bridge is especially suited for calibration with a Weston cell for maximum voltage measurement near, but not exceeding, 1.100 volts. For this range the calibration should be one millivolt per centimeter and **BF** is set as follows: with $\mathbf{E_s}$, for example, equal to 1.0186 or 1018.6 millivolts the span needed is 1018.6 cm. This requires 10 full wire lengths plus 18.6 cm on the slide wire, a setting shown in Figure 8.

After these connections have been made, tap the switch **S** and adjust **D** until the needle of the galvanometer indicates zero current. It is then safe to remove the protective high resistance **H** and make a final careful setting of **D** for the desired calibration. If the changes produced by an adjustment of **D** are too great, a parallel rheostat should be added to **D**. After the final adjustment of **D** has been made, the working battery circuit must remain unchanged for the rest of the experiment. Recheck after the readings on cell $\mathbf{E_x}$ are taken.

Electromotive Force of Test Cell: Connect the cell $\mathbf{E_x}$ to be studied into the galvanometer circuit. Determine the electromotive force of this cell by adjusting the traveling plug **B** and slide **F** until the galvanometer again registers no current when the tap switch is used. Remember to protect the circuit by finding a near balance first with the protective resistance in the galvanometer circuit. The final reading of **F** plus the full wire lengths spanned will be the emf of $\mathbf{E_x}$. If, for example, the span is 6 full wire lengths plus 32.5cm on the slide wire, that is 632.5cm, with a calibration of one millivolt per centimeter, the emf of $\mathbf{E_x}$ is 0.6325 volt.

Terminal Voltages of Test Cell: Now add the shunt resistance $\mathbf{R_v}$ to the terminals of the cell. Set the shunt resistance for 150 ohms and find the new balance span. This gives the potential difference readings of the cell terminals, when the cell is supporting a small current in the shunt circuit. Repeat the above for increasing currents using external resistance values of 100, 60, 30, 15, 10, 8, 6, 4, 3, 2, and 1 ohms.

A. Tabulate the external resistance, terminal voltage, cell current and internal resistance values for the several readings.

B. Plot a curve with external resistance as ordinate against terminal voltage as abscissa. Interpret the graph.

C. Plot a curve with terminal voltage as ordinate against current as abscissa. Determine the value of the internal resistance of the cell from this graph and compare with the values obtained in Parts A and B.

4C. Questions

1. What is the essential feature of a volt-meter designed to read the electromotive forces of cells with minimum error?

2. What is the maximum current which the test cell used in this experiment can furnish?

3. What determines the value of the electromotive force of a cell?

4. What factors, besides the internal resistance potential drop, can alter the terminal voltage of a cell supplying energy to a circuit? How are these effects minimized in the construction of cells?

5. Prove that the negative of the slope of the curve, **V** vs. **I**, (Figure 5) is the internal resistance of the cell.

6. What is the significance of each of the intercepts of the graph in Figure 5?

7. A certain voltmeter has a resistance of 75 ohms. What would this voltmeter read if connected to the cell tested in this experiment?

4D. Additional Experiments

Additional experiments using this apparatus are described in the following Selective Experiments in Physics (SEP):

71996-5, "Ohm's Law." The purpose of this SEP is to study the application of Ohm's Law to simple circuits; in particular, to measure the variation of:

- current with resistance in a circuit of constant potential difference
- potential difference with resistance when the current is constant
- potential difference with current when the resistance is constant

71996-53, "Ohm's Law." The purpose of this SEP is to study the application of Ohm's Law to simple circuits; in particular, to observe the variation of:

- current as a function of potential difference across a given metallic conductor
- current as a function of resistance when the voltage is kept constant
- voltage as a function of resistance when the current is constant

71996-54, "Ohm's Law in Simple Circuits." The purpose of this SEP is to study Ohm's Law and to investigate the factors on which the resistance of a metallic conductor depends.

Each of these experiments is available in a package of 10 identical experiments from Central Scientific Company.

5. Accessories

Most of the apparatus required for SEP experiments using the two-meter potentiometer slidewire bridge will probably be found in the laboratory. However, if the following items are needed, they are available from Central Scientific and are listed below.

Description	Cat. No.
Square 1.5 VDC Dry Cell Battery	79145-01
Eppley Cell, Student Form with Protective Resistance	79427
Student Galvanometer	82102-01
44-Ohm Tubular Rheostat	82910-12
Single Contact Key	84210
Double-Pole, Double-Throw Knife Switch	84321

6. Maintenance

The Two-Meter Potentiometer Slidewire Bridge needs no special maintenance. If you should experience any difficulty with this piece of equipment, please contact Central Scientific Company, giving details of the problem. To ensure better service, please do not return any apparatus to Central Scientific Company until we have sent you authorization.

7. Copyright Notice

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