

## EXPERIMENT 7 THE WHEATSTONE BRIDGE

### I. THEORY

It may be shown by experiment that the electrical resistance of a wire is directly proportional to its length and inversely proportional to its cross-sectional area. The resistivity  $\rho$  is then defined by the equation

$$R = \rho L/A$$

The Wheatstone Bridge is an instrument designed for measuring an unknown resistance by comparing it with a known, or standard, resistor.

In the schematic diagram in section IV,  $R_1$  is an unknown resistor whose value is to be determined. Three known resistors are required, as well as a galvanometer and a cell (battery). In use, the bridge is "balanced" by adjusting one or more of the known resistors until there is no current through the galvanometer. When this is done,  $R_1$  may be calculated from the three known resistors by an equation derived below.

Although four separate resistors may be used, there are simpler forms of the bridge.

In the box form of bridge, used in the Kirchhoff's Rules Experiment,  $R_2$  consists of a 4-dial resistance box with one dial for each of thousands, hundreds, tens and units of ohms.  $R_3$  and  $R_4$  are combined into the multiplier dial.

In the slide wire form of bridge, used in this experiment,  $R_2$  is a plug resistance box.  $R_3$  and  $R_4$  together make up a one-meter length of uniform wire. Point D is a sliding contact on the wire.  $S_1$  is a switch whose purpose is to avoid running the cell down when the bridge is not being used.  $S_2$ ,  $R_5$ , and G together make up the "three-button galvanometer". Pushing different buttons  $S_2$  varies the sensitivity of the galvanometer by selecting different values of  $R_5$ .

When the current through the galvanometer has been reduced to zero by moving the sliding contact point D, then points B and D must be at the same potential. Also, since no current is going through the galvanometer, the current through  $R_1$  must be the same as the current in through  $R_2$ ; it is labeled  $I_1$ . For the same reason, the current through  $R_3$  must be the same as the current through  $R_4$ ; it is labeled  $I_2$ .

The fact that  $V_{AB} = V_{AD}$  means that  $I_1 R_1 = I_2 R_3$ . The fact that  $V_{BC} = V_{DC}$  means that  $I_1 R_2 = I_2 R_4$ . Dividing these two equations, we obtain  $R_1/R_2 = R_3/R_4$ .

Since  $R_3$  and  $R_4$  are two parts of the same continuous piece of wire, they have the same resistivities and cross-sectional areas. It follows that the ratio of their resistances is the same as the ratio of their lengths,  $R_3/R_4 = L_3/L_4$ .

As a result,  $R_1/R_2 = L_3/L_4$  or  $R_1 = R_2 L_3/L_4$ .

The main advantage of the slide wire form of Wheatstone Bridge is that it requires only one standard resistor,  $R_2$ . In addition, its open design allows the student to see exactly how it works. The box form of bridge, on the other hand, is more accurate and quite portable.

## II. LABORATORY PROCEDURE

1. Use the Resistor Color Code in the introduction of this manual to determine the nominal resistances and tolerances of all resistors on the resistor board. If the bands are too worn to be seen clearly, obtain a magnifying lens from the instructor.
2. Refer to the semi-pictorial diagram in section IV. The letters A-D refer to the same points as in the schematic diagram. Connect resistor A on the board of resistors, the first "unknown" resistor, between bars A and B. Connect the plug resistance box, the standard resistor, between bars B and C. Connect the left end of the one-meter wire to bar A and the right end to bar C.
3. Clean the contacts of the switch with a piece of emery cloth. Connect one terminal of the switch to bar C; connect the other terminal to either terminal of the cell. Connect the other terminal of the cell to bar A. Leave the switch open.
4. See if any of the buttons of the galvanometer is stuck in the depressed position; if so, rotate it to release it. Connect one terminal of the galvanometer to bar B; connect the other terminal to the long bar D.
5. Set the plug resistance box to a resistance of the same order of magnitude as the unknown resistor, by removing enough plugs to total the desired resistance; then twist and push in all of the remaining plugs.
6. Close the switch  $S_1$ . Place the sliding contact near the left end of the wire, and hold one end of it down. Depress the left button of the galvanometer and observe which way the needle deflects. In the rest of this experiment, whenever the needle deflects in this direction, you will know that the slider is too far to the left for balance.
7. Move the slider to a point near the middle of the wire. Hold one end of the slider down, and momentarily depress the left button of the galvanometer. Observing the direction of the deflection, and remembering the results of step 6, move the slider to a new position and repeat the test. (Do not move the slider while holding it down, as that would scrape bits of metal off of the wire and result in a non-uniform cross-section. This will lead to the failure of the ratio of  $R_3$  to  $R_4$  to equal the ratio of  $L_3$  to  $L_4$ .) When the galvanometer deflection has been reduced to zero for the left button of the galvanometer, use the middle button and, finally, to the right button. When there is no deflection, using the right button of the galvanometer, the bridge has been balanced. Record the nominal value of the resistance, the slide wire position ( $L_3$ ), and the standard resistance ( $R_2$ ).

8. For a second measurement of the same "unknown" resistor, change the setting of the plug resistance box by *at least* ten percent, and balance the bridge again. Again record the slide wire position and the standard resistance.
9. Repeat steps 5-8 for all of the remaining resistors on the board.
10. Record the gauge number of the spool of wire.
11. Repeat steps 5, 7 and 8 for the spool of wire. Its resistance should be between 10 and 70 ohms.

### III. CALCULATIONS

1. Make a table containing the following quantities: nominal resistance, slide wire length  $L_3$ , standard resistance, measured resistance. (No nominal value can be listed for the spool.) Each resistor, including the spool of wire, is listed twice.
2. Make a table containing the following quantities: nominal resistance, average measured resistance, and percent difference (between the nominal value and the average measured value). List the average measured value of the spool of wire even though no nominal value or percent difference can be listed.
3. Use the following table to determine the diameter of the wire on the spool:

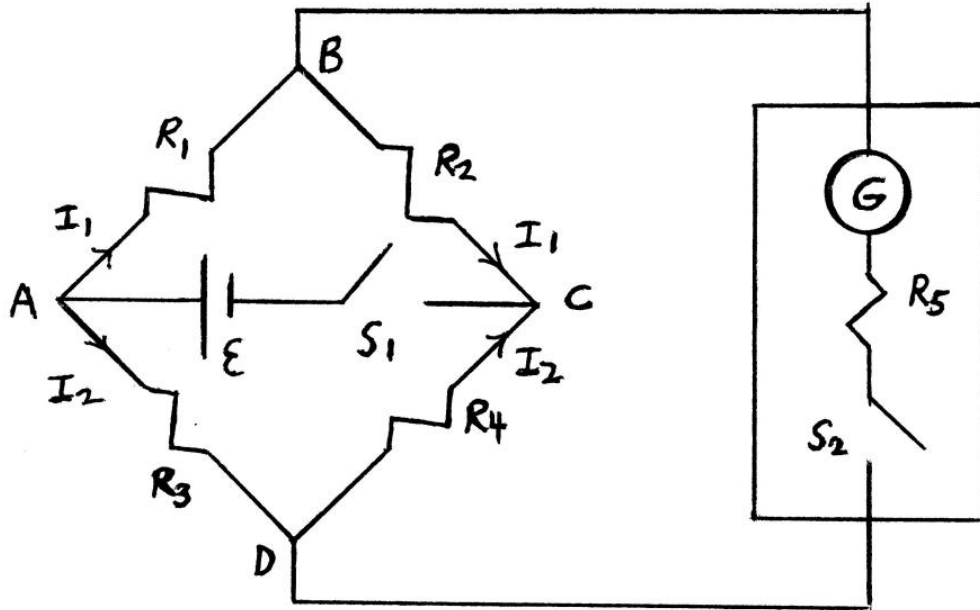
gauge number	21	22	23
diameter (mm)	0.723	0.644	0.573

Calculate the cross-sectional area of the wire in  $\text{m}^2$ .

4. Using the resistivity of copper,  $1.72 \times 10^{-8} \Omega\text{-m}$ , calculate the length of the wire on the spool, which should be in the range of 150 m to 1500 m.
5. As a reasonableness check calculate the mass of the copper in the wire on your spool. Use the diameter given in the table, the length you calculated and the density of copper. Is your calculated mass reasonable?

IV. DIAGRAMS

Schematic



Semi-Pictorial

