THE WHEATSTONE BRIDGE

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PROBLEM

The Wheatstone bridge is an electrical circuit used to measure resistance and for the precise comparison of resistances.

INTRODUCTION

Sir Charles Wheatstone is most famous for this device but never claimed to have invented it - however, he did more than anyone else to invent uses for it, when he 'found' the description of the device in 1843. The first description of the bridge was by Samuel Hunter Christie (1784-1865) in 1833.

ABSTRACT

This lesson is designed for Physics class which has already studied electric circuit, series & parallel connection, the behavior of current, resistance, the color codes and Ohm’s law, including the related definitions and circuit diagrams.

The unit is designed to provide the student with several opportunities to connect the new understanding with knowledge that they may have acquired previously, either through previous physics units or in a physical science course. It further helps to expand the knowledge towards learning new concepts. The students are expected to perform the experiment in a group of four under the guidance of the teacher.

The Wheatstone bridge is an electrical bridge circuit used to measure resistance. It consists of a common source of electrical current (such as a battery) and a galvanometer or a multimeter that connects two parallel branches, containing four resistors, three of which are known. One parallel branch contains one known resistance and an unknown (Rx, as in Figure 1); the other parallel branch contains resistors of known resistances (R₁ and R₂). In order to determine the resistance of the unknown resistor, the resistances of the other three are adjusted and balanced until the current passing through the multimeter decreases to zero.

Due to their outstanding sensitivity, Wheatstone bridge circuits are very advantageous for the measurement of resistance, inductance, and capacitance.
ALIGNMENT WITH THE NATIONAL AND STATE STANDARDS

Physics Course
Inquiry, Process and Problem Solving; uses science process skills in laboratory or field investigations, including observation, classification, communication, metric measurement, and prediction, inference, collecting and analyzing data.
SCSh2 Students will use standard safety practices for all classroom laboratory and field investigations.
SCSh3 Students will identify and investigate problems scientifically
SCSh4 Students will use tools and instruments for observing, measuring, and manipulating scientific equipment and materials.
SCSh5 Students will demonstrate the computation and estimation skills necessary for analyzing data and developing reasonable scientific explanations.
SCSh8 Students will understand important features of the process of scientific inquiry. Students will apply the following to inquiry learning practices; scientific investigators control the conditions of their experiments in order to produce valuable data

THEMES AND CONCEPTS

Electric potential difference, resistance, circuit symbols, fundamentals principles of DC and AC series and parallel circuits, Ohm's Law, SI units, and test equipments.

OBJECTIVES

Students to apply the main concepts developed throughout the unit and to explain the techniques used to make discoveries through a series of controlled, laboratory experiments to:

- Determine the value of an unknown resistance using the Wheatstone bridge.
- Verify the linear dependence of wire resistance upon length and cross section (Extended part of the lab).

LEARNING OUTCOME

- Enables to reinforce the previously learnt concepts.
- Will help to validate the known theories and concepts.

EQUIPMENTS
Wheatstone bridge (Slide-wire assembly), decade resistance box (0.1 to 10 ohms), multi range galvanometer/multimeter, unknown resistors in range 1 to 100 ohm, Tap key, Connecting wires, 1.5 v power source.

**Theory**

The most convenient, and also the most accurate method of measuring resistances of widely different values are by means of the Wheatstone bridge. A Wheatstone bridge is a circuit consisting of four resistors arranged as shown in Fig. 1. It is used for finding the value of an unknown resistance by comparing it with a known one. Three known and adjustable resistances are connected with the unknown resistance, a galvanometer/multimeter, a power supply, and a key, as shown in Fig. 1, for a condition of balance, so that no current flows through the galvanometer. Hence the current through $R_1$ is the same as the current through $R_2$, and the current through $R_3$ is the same as that through $R_4$.

Also, the potential drop across $R_1$ is equal to that across $R_3$.

\[ i_1R_1 = i_2R_3 \quad (1) \]

Similarly, the potential drop across $R_2$ is equal to that across $R_4$

\[ i_1R_2 = i_2R_4 \quad (2) \]

Dividing the first equation by the second, one finds the relation

\[ \frac{R_1}{R_2} = \frac{R_3}{R_4} \quad (3) \]

Therefore, if three of the resistances are known, the fourth may be calculated by using the above relation.
THEORY refer simulation for working a Wheatstone bridge:
http://fysikk.hfk.vgs.no/DEMOER/Wheatstone/Bridge(1).htm

Physical Layout of the Wheatstone Bridge

Figure 2

We will use a slide-wire Wheatstone bridge, in which the two resistors $R_1$ and $R_2$ are two portions of a single, uniform Ni-Cr wire. Electrical contact is made at some point along the wire by a sliding contact (this contact corresponds to point A). The two portions of the wire on either side of the contact have resistances $R_1$ and $R_2$, and the ratio $R_2/R_1$ is the same as the ratio of the lengths of the two portions of wire $L_2/L_1$. The lengths are readily measured with a meter stick which the wire rests upon.

$$R_x = R_k \frac{R_2}{R_1} = R_k \frac{L_2}{L_1}$$

Equation (3) can be written as:

Procedure

1. Connect the slide wire form of the bridge as shown in Fig. 2. Let $X (R_X)$ be the
unknown resistance of resistor No. 1 and let $R (R_k/R_3)$ be the standard resistance. Have the circuit approved by the instructor. Read the color code and record the values of your three resistors.

2. Measure the resistance of No. 1 with this bridge. To obtain a balance, set the sliding key in the center of the bridge wire and adjust the control key, $C$, until a minimum deflection of the galvanometer or when the voltage reading drops to zero. When the bridge is balanced, measure $L_1$ and $L_2$ using a meter scale.

3. Record the values of the standard resistance and of the sliding key. Record two more readings by altering the $R_k$ value and calculate the average to compare it with the resistance value based on color code.

4. Similarly measure the resistance of resistors No. 2 and 3 by repeating procedural steps 2 and 3.

5. Compare the average values obtained from the Wheatstone bridge for each of the resistances against the values from the color code.

Table I

<table>
<thead>
<tr>
<th>RESISTOR # (Ω)</th>
<th>RESISTANCE (based on color code) (Ω)</th>
<th>$R (R_k)$ (known resistance value) (Ω)</th>
<th>$L_1$ (m)</th>
<th>$L_2$ (m)</th>
<th>UNKNOWN RESISTANCE $R_X$ (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
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<td></td>
<td></td>
<td>$R_X = R_k \frac{R_2}{R_1} = R_k \frac{L_2}{L_1}$</td>
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<td>2</td>
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**CALCULATIONS**

1. Calculate the value $R_X$ (unknown), using equation 4.
ANALYSIS

1. Calculate the maximum relative error in the measured resistance of table I. The relative error in the standard is 0.2%.
2. Would a change in terminal voltage of the power supply affect the operation of the bridge? Explain.

RUBRIC

<table>
<thead>
<tr>
<th>5 Points</th>
<th>4 Points</th>
<th>3 Points</th>
<th>2 Points</th>
<th>1 point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct circuit diagram, getting the connections right, showing step-by-step calculations and computing the answers within the expected measurement error values, using right SI units, and demonstrating high level of understanding of concepts.</td>
<td>Taking help to complete circuit connections, showing step-by-step calculations and computing the answers within the expected measurement error values, using right SI units, and demonstrating high level of understanding of concepts.</td>
<td>Taking help to complete circuit connections, skipping step-by-step calculations and representation of SI units. The final answer showing an error exceeding 0.10%, and demonstrating average level of understanding of concepts.</td>
<td>Unable to complete circuit connections, wrong calculations, answer exceeding the error limit, unable to analyze the problem, and occasional misunderstanding of concepts.</td>
<td>Incomplete, unclear, and major misunderstandings of concepts.</td>
</tr>
</tbody>
</table>

POST QUIZ

1. Name two advantages of a Wheatstone bridge over an ordinary ohmmeter.
2. What is the formula for the total resistance of two resistors in parallel? Consider two
resistors $R_1 = 3\Omega$ and $R_2 = 200\Omega$. What is the total resistance of these two resistors in parallel? Give your answer to the nearest ohm.

3. Consider Fig. 1 and recall that the total resistance of the Ni-Cr wire is $2\Omega$. If $R_k$ and $R_x$ are both very, very large compared to $2\Omega$, how much current flows through the Ni-Cr wire?

4. Suppose an unknown resistance $R_x$ is measured with the bridge circuit shown in Fig. 1 and the result is $R_x = 8.65\Omega$. The 6V battery is then replaced with a 10V battery and $R_x$ is re-measured. What is the new measured value of $R_x$?

5. A sample of copper wire is 100m long and has a diameter of 0.250 mm. Its resistance is determined to be 38.0$\Omega$. What is the resistivity of the copper in this wire?

**EXPANSION:** To demonstrate the linear relationship between resistance and length of a wire conductor.

For this experiment, resistors, two of the known resistors ($R_1$ and $R_2$) are provided by a 1.00 m long conducting wire that may be tapped at any point along its length to divide its total resistance into two parts. The resistor $R_K$ has a known resistance that is measured with a multimeter. The resistor $R_x$ is the resistor of unknown resistance. By moving the point at which the 1.00 m long wire is tapped, a situation can be reached in which the current flowing through the galvanometer is zero. When this occurs, this means that the potential difference across the galvanometer is zero. At this point, we let $I_1$ designate the current flowing through resistors $R_1$ and $R_2$ and $I_2$ be the current flowing through resistors $R_K$ and $R_x$, then

$$I_1 \cdot R_1 = I_2 \cdot R_K$$
$$I_1 \cdot R_2 = I_2 \cdot R_x$$

Dividing the second of these equations by the first, and solving for $R_x$, we get:

$$R_x = R_2 \cdot R_K / R_1$$

Since $R_1$ and $R_2$ are formed from the same wire conductor, when equation 1 substituted into the last equation, the result is:
\[ R_x = \frac{L_2 R_K}{L_1} \]  \hspace{1cm} (2)

Where \( L_1 \) and \( L_2 \) are the lengths of the conducting wires forming \( R_1 \) and \( R_2 \).

In this experiment the use of equation 2 above depends upon the linear relationship between resistance and length of a conducting wire described in equation 1. Therefore, verification of the linear relationship between resistance and length of a conducting wire of uniform cross-sectional area must precede measurements with the Wheatstone bridge.

The first objective of this experiment is to verify that linear relationship. This will be accomplished by placing a constant potential difference across the full length of the wire and measuring the voltage drop across a variety of partial lengths of the wire. Since the current in the wire is constant, the voltage drop across a given portion of the wire is proportional to the resistance of that portion of the wire. Thus, a graph of voltage drop versus wire length should be a straight line. The slope gives the potential gradient value (V/L).

Data

The data necessary for this lab is:

1. A table of data from the linearity measurements.
2. A table with data from the Wheatstone bridge measurements.
3. Plots of voltage drop versus length of wire conductor that includes a regression line (trend line) and its equation.

Results

1. A statement regarding the verification of the linear relationship between resistance and length of a wire conductor.
2. A statement regarding the use of the Wheatstone bridge apparatus in the configuration used in this experiment for measuring resistance