Wheatstone Bridge
Saddleback College Physics Department

Purpose

Using the Wheatstone Bridge apparatus, determine the resistance of three different unknown resistors and compare these to their advertised values.

Theory

When a potential (voltage) difference V is applied across a resistor, current I flows through the resistor in accordance with **Ohm's Law:**

$$V = IR \qquad \text{(Eq. 1)}$$

where R is the **resistance** of the resistor, measured in ohms. 1 Ω = 1 V/A

One might suppose that resistance can be easily determined by connecting a resistor to a voltage source (such as a battery), measuring the potential difference V across the resistor with a voltmeter, then dividing by the current I through the resistor as measured by an ammeter. Having these meters in the circuit, however, can affect the quantities being measured.

Suppose that the voltmeter is connected directly across the unknown resistance as shown in Figure 1, where current I passes through the resistor. The voltmeter draws an additional current i, however, so the ammeter reading will be too high ($I + i$), and the calculated value of R will then be too low.

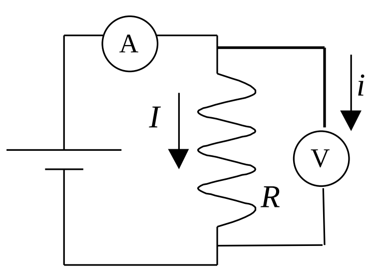

Figure 1

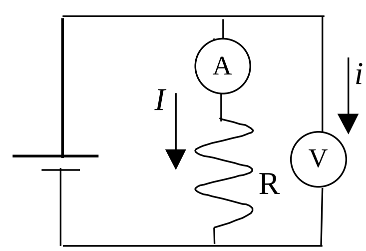

Figure 2

Another scenario allows for the voltmeter to be connected across both the resistor and the ammeter, as shown in Figure 2. The ammeter measures the correct current I, but now the voltmeter reading will be too large since some voltage will drop across the ammeter as well. In this case, the value obtained for R will be too high.

This lab uses the Wheatstone Bridge method to determine an unknown resistance R_x (Fig. 3). This circuit avoids most of the difficulties of the ammeter-voltmeter method described above. No meter readings need be taken except for a judgment of when the current measured by a **galvanometer** has been reduced to zero. In Figure 3, the galvanometer is represented by a **G**.

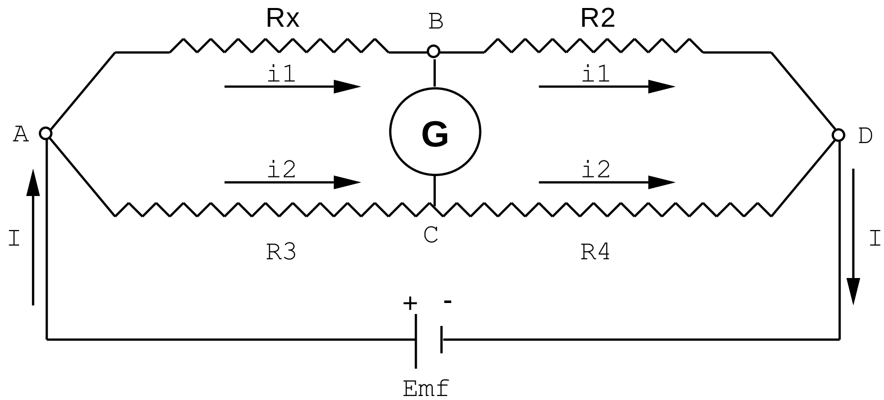

Figure 3

Ohm's Law (Eq. 1) states that if there is no voltage difference V across a resistor, then no current flows through it. If points B and C are at the same voltage, then the voltage difference across the galvanometer will be zero, so it draws no current. This is the situation shown in Figure 3.

Current I coming from the battery splits at point A into two **branch currents** i_1 and i_2, passing through resistors R_x and R_3. Since no current flows from one branch to the other through the galvanometer, these currents continue on through resistors R_2 and R_4, recombining at point D.

Points B and C are at the same voltage, so the voltage drops across R_x and R_3 will be equal, and the voltage drops across R_2 and R_4 will also be equal.

$$V_x = V_3$$
$$V_2 = V_4 \qquad \text{(Eqs. 2)}$$

The voltage drops and the branch currents are related through Eq. 1 (for example, $V_x = i_1 R_x$). In your report, show that there exists a relationship between the four resistances:

$$\frac{R_x}{R_2} = \frac{R_3}{R_4} \qquad \text{(Eq. 3)}$$

In this experiment, the "slidewire" form of the Wheatstone Bridge will be used. A length of wire representing the lower branch is strung between points A and D. A sliding contact (the "probe") divides the total resistance of the wire into sections R_3 and R_4.

The resistance of a wire is given by:

$$R = \frac{\rho L}{A} \qquad \text{(Eq. 4)}$$

where ρ is the **resistivity** of the material, L is the length, and A is the cross-sectional area.

Since ρ and A are presumed to be equal throughout the length of the slide-wire, the ratio of the resistances is just the ratio of the wire lengths:

$$\frac{R_3}{R_4} = \frac{L_3}{L_4} \qquad \text{(Eq. 5)}$$

Combining Eq. 3 and 5, and solving for the unknown resistance R_x gives:

$$R_x = \frac{L_3}{L_4} R_2 \qquad \text{(Eq. 6)}$$

Equipment

3.0 V DC power supply
Slidewire apparatus
Galvanometer
Probe
3 unknown resistors
1 known resistor (1 kΩ)

Procedure

Choose three different unknown resistors and note their numbers. Set up the circuit according to Figure 3, with the probe at point C. Install one of the unknown resistors at R_x and make the reference resistor $R_2 = 1$ kΩ.

IMPORTANT NOTE:

The galvanometer is an extremely sensitive instrument. Only small currents should be allowed to pass through it.

Use the galvanometer in short bursts at first. When you begin testing for current flow, just tap the tip of the probe on the wire, noting the direction of deflection. Move the probe and continue tapping it on the wire until the galvanometer does not go off-scale. Only then should you hold the probe on the wire.

Once you have found the point on the slidewire where the galvanometer reads zero, record the two lengths L_3 and L_4 and the errors (uncertainties) δL of these measurements.

Repeat the experiment for two more unknown resistors.

Analysis

Use Eq. 6 to calculate each unknown resistance.

For each length L, calculate the relative error $\frac{\delta L}{L}$. The reference 1 kΩ resistor has a **tolerance** of 5%, so let $\frac{\delta R_2}{R_2}$ = 0.050. Using the rules of error propagation, calculate the relative error $\frac{\delta R_x}{R_x}$ of the unknown resistance and the associated range of experimental values ($R_x \pm \delta R_x$).

For example, if R_x = 2000 Ω and $\frac{\delta R_x}{R_x}$ = 0.060, then δR_x = (0.060)(2000 Ω) = 120 Ω, so the range of experimental values would be 1880-2120 Ω.

Once you have completed this analysis, your lab instructor will reveal the advertised values of your unknown resistances, which also have a tolerance of 5%. Compare your range of experimental values to the advertised value.

For example, suppose the advertised value was 2200 Ω. The 5% tolerance allows this value to be off by as much as (0.050)(2200 Ω) = 110 Ω, so the range of acceptable values is 2090-2310 Ω. This overlaps with the range of experimental values, indicating that the experiment was successful.

Followup Questions

1. Which of your unknown resistances had the smallest relative error? Why?

2. What effect (if any) would using a different voltage supply have on this experiment?

Extra Credit (2 points):

Switch the galvanometer and the battery and repeat the experiment for one of your unknown resistors. The galvanometer should be connected between points A and D, and the battery between points B and C.

Show theoretically that when the current through the galvanometer is zero, the ratio L_3/L_4 should be the same as it is when the circuit is set up normally (Fig. 3).