

# Wheatstone Bridge

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## Theoretical Background

At first, one might suppose that resistance can be satisfactorily measured or calculated by placing a resistor in series with a power supply, finding the potential difference across the resistor (with a voltmeter in parallel) then dividing by the current through the resistor (as read from an ammeter in series). However, a more detailed analysis of such an arrangement reveals certain difficulties and inaccuracies discussed below. Since most common meters have solid state digital readouts, the physics is more readily demonstrated with a moving coil current detector called a galvanometer. Galvanometers are the main component of analog meters.

Suppose, for example, that the voltmeter is connected directly across the unknown resistance as shown in Figure 1. A small current  $i$  is required to deflect the moving coil of an analog voltmeter. This current will then flow through the ammeter in addition to the main current  $I$  through  $R$ . The ammeter reading will be too high and quotient of the two meters readings (which is  $R$ ) will be too low.

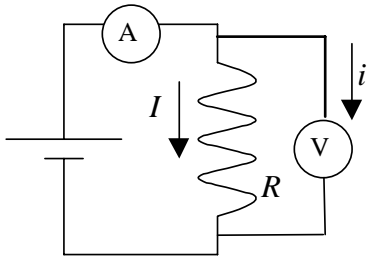


Figure 1.

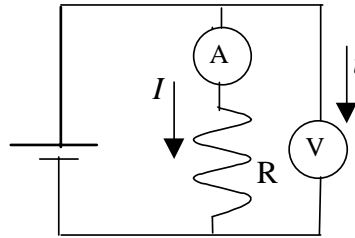


Figure 2.

Another scenario allows for the voltmeter to be connected across both the resistor and the ammeter, as shown in Figure 2. The voltmeter reading will be too large since it measures the potential difference across the ammeter as well. In this case, the value obtained for  $R$  will be too large.

It is true that the error may be reduced in the first arrangement if  $R$  is sufficiently small compared to the voltmeter resistance, or in the second arrangement if  $R$  is large compared to the resistance of the ammeter, but, in general, a correction must be made in either case to obtain the desired accuracy.

A further difficulty arises from the fact that the meter readings contain uncertainties inherent to the construction of the meter. These uncertainties depend upon such factors as the size of the smallest division on the meter scale and the reliability of the calibration. When the two meter readings are divided to calculate resistance using Ohm's law, the uncertainties are compounded.

For the most accurate measurement of resistance, the Wheatstone Bridge circuit is used. This circuit avoids most of the difficulties of the ammeter-voltmeter method. This is a null method, in which no meter reading needs be taken except for a judgment of when the deflection of a galvanometer has been reduced to zero.

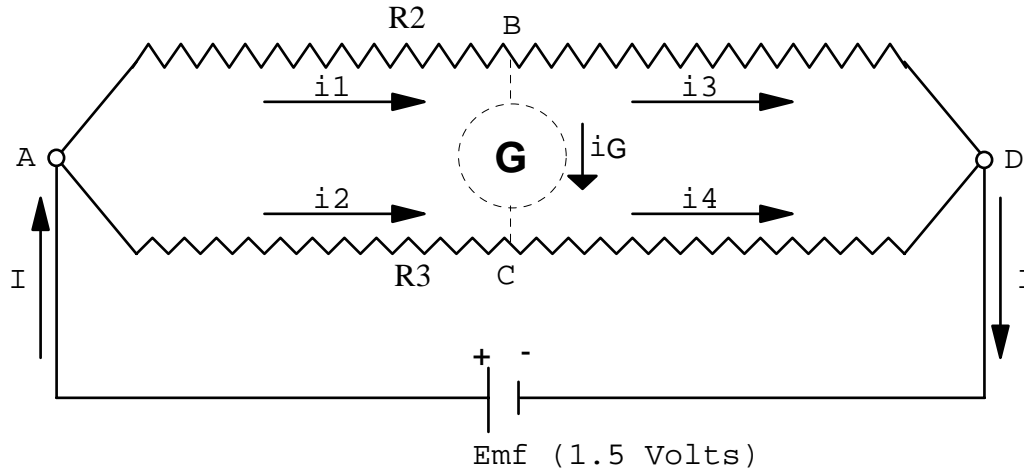


Figure 3.

Suppose that two different resistances are connected in parallel across a dry cell of  $\text{emf} = 1.5 \text{ V}$  and negligible internal resistance as shown in Figure 3. Then the common point D will have the same electric potential as the negative terminal of the cell, which will be assumed to be  $0 \text{ V}$ , and the potential at the point A will be  $+1.5 \text{ V}$ . The total potential drop is the same by either path traveling from A to D since the two resistances are in parallel. Now, if a point B is selected on the upper branch, the potential will be below that of A but above that of D. For example, if the drop in potential from A to B were  $0.6 \text{ V}$ , then the potential at point B would be  $0.9 \text{ V}$ . If some other point C were selected at random along the lower path, there is little chance of it having the same potential as that of B. Point C, for instance, might be  $0.7 \text{ V}$  below A, bringing its potential to  $0.8 \text{ V}$ . The potential at B would then be  $0.1 \text{ V}$  above C. If you connect a current indicator, such as a galvanometer, across the two points it would show a current flowing from B to C.

Examining the current flow through the circuit in Figure 3 will illuminate the purpose of this experiment. In the case described in the previous paragraph (potential at B is greater than C) the current  $I$ , assumed to come from the positive terminal of the dry cell, would divide at A into two branch currents:  $i_1, i_2$  which are generally considered to be unequal.  $i_1$  would then divide again at B, creating  $i_G$ , which flows through the galvanometer to C. The remainder of  $i_1$  will become  $i_3$  and continue along the upper branch of the circuit. The current marked  $i_4$  is given to be  $i_2 + i_G$ , according to Kirchoff's Law.

Now, consider that the point C on the lower branch is perhaps not selected at random. Instead, it is located at a point where its potential would be the same as B. There would be no current flow

between B and C and thus no current flow through the galvanometer. The current  $i_1$  would continue unchanged along the upper branch to its termination at D. See Figure 4.

Herein lies the heart of the Wheatstone Bridge experiment. Point C can be located at any point along its branch until the deflection of the galvanometer is reduced to zero, thus indicating that the resistance along the top is the same as the bottom. So, it follows that if B and C are at the same potential, then the voltage drop from A to B and from A to C must be the same, in addition the voltage drop from B to D and C to D must be the same. Using Kirchoff's Loop Law in the small loops, we find that  $R_x i_1 = R_3 i_2$  and  $R_2 i_1 = R_4 i_2$ . Dividing these equations, we get a nice

relation between the resistances: 
$$\frac{R_x}{R_2} = \frac{R_3}{R_4} \text{ (Eq. 1)}$$

There is a small problem in achieving the same potential between B and C. Various forms of variable resistors can be used, but for this particular experiment, the slidewire form of the Wheatstone Bridge will be used. A one-meter length wire, made of an alloy that has a much higher resistance than that of a similar copper wire, is strung between points A and D, forming the lower part of the circuit. A sliding contact divides the total resistance of the wire into pieces

$R_3$  and  $R_4$ . The resistance of a wire is given by  $R = \frac{\rho L}{A}$ , where  $\rho$  is the resistivity of the material, L is the length, and A is the cross-sectional area of the wire. Looking at Eq. 1, we can replace  $R_3$  and  $R_4$  using the formula for the resistance of the wire. Thus, the relation becomes

$$\frac{R_x}{R_2} = \frac{L_3}{L_4},$$

requiring only the resistance  $R_2$ , and the lengths of the wire determined by the

position of the slider to find the unknown resistance,  $R_x$ .

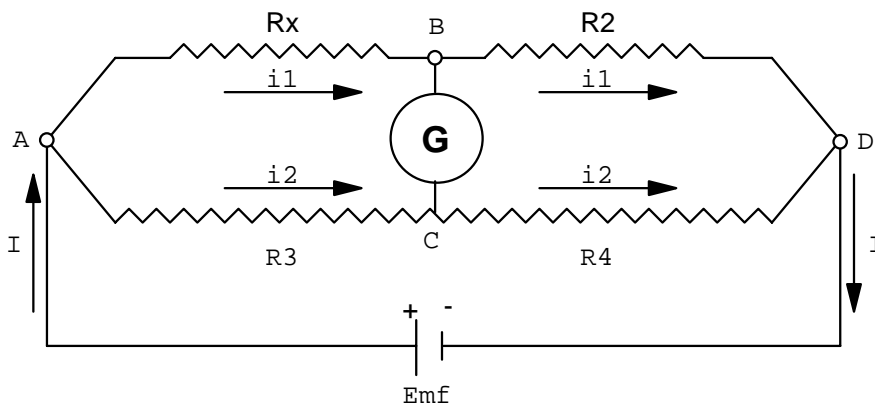


Figure 4.

## Purpose

Using the Wheatstone Bridge apparatus, determine the resistance of three different unknown resistors and compare these to their corresponding theoretical resistances.

## Theory

Derive the relationship  $\frac{R_x}{R_2} = \frac{L_3}{L_4}$ .

## Equipment

Dry cell  
Slidewire apparatus  
Galvanometer  
Test leads, alligator clips & test lead *tip*  
3 unknown resistors  
Resistance box  
Digital Ohmmeter  
Wheatstone Bridge Box (shared by class)

### **IMPORTANT NOTE:**

*The galvanometer is an extremely sensitive instrument. Please do not play with it and be very conscious about the current that travels through it. Only small currents should be allowed to pass through it and some protection should be provided. If a three-button galvanometer is provided, use only the first button until the balance is nearly made, then shift to button 2 and finally to button 3, which cuts out all series resistance in the meter. NOTE: The galvanometer you use may only have two buttons which can be positioned in 3 different ways/combinations. The 3 combinations are equivalent to the 3 buttons referred to below.*

When you connect all of the circuit components and power the circuit, use the galvanometer in short bursts. When you first start testing for current flow, depress button 1 on the galvanometer and just tap the tip of the test lead on the slidewire, noting the direction of deflection. Adjust your slidewire and/or variable resistance box and continue tapping the tip of the test lead on the slidewire until the deflection on the galvanometer does not *peg* all the way over. Move to button 2 and tap the tip of the test lead on the slidewire, re-adjusting the slidewire until the galvanometer deflection is less. Finally, use button 3 (if available) and repeat tapping/adjustment procedure. *If you follow these precautions, none of our galvanometers will be damaged.*

## Procedure

- a. Set up the circuit according to Figure 4 below. Connect one of the resistors at the position marked  $R_x$  and set the resistance box to 10 ohms at  $R_2$ . Move the slider key to the center of the slidewire.

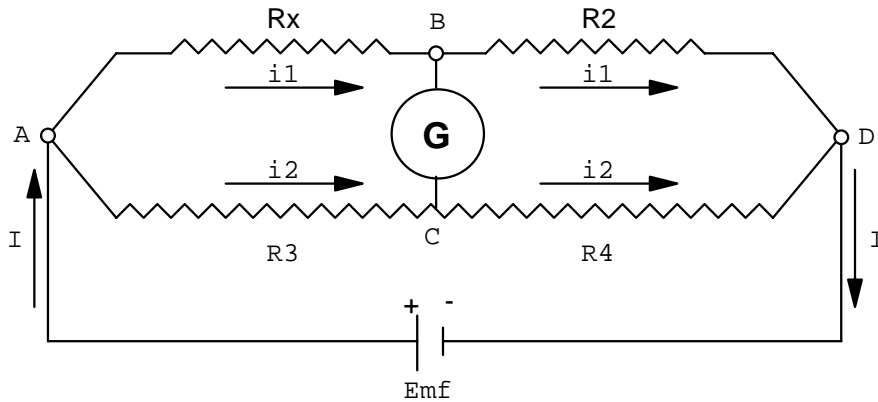


Figure 4.

- b. Quickly tap the slider key and note which way the needle deflects. Change  $R_2$  to 100 ohms and tap the slider key again. The needle should deflect in the opposite direction. If it does, then the correct range for  $R_2$  has been determined and you may proceed to a closer balance.
- c. Begin adjusting  $R_2$  upwards from 10 ohms until the deflection becomes less and less. Once a near perfect balance has been achieved, switch to button 2 on the galvanometer and move the slider key to the left or right and note the deflection. Once you have found the balance point on the slidewire, record the two lengths as accurately as possible.
- d. Note: It is best to have the slider nearest the center; it produces the most accurate results.
- e. Solve for  $R_x$  by rearranging Eq. 1.
- f. Repeat experiment with at least two more unknown resistors.

## Other Investigations

- a. Reverse the polarity of the battery. Observe and record the effect, if any.
- b. Interchange the battery and galvanometer and observe the effect. Explain your prediction and explain/justify your observation.
- c. Obtain the resistance of an unknown resistor with the Wheatstone Bridge, a Wheatstone Bridge Box (if possible), and an Ohmmeter. Which of these measurements is likely to be most accurate? Why?