

615-4540 (10-215) Wheatstone Bridge

Warranty and Parts:

We replace all defective or missing parts free of charge. Replacement parts may be ordered. We accept MasterCard & Visa, School P.O. All products warranted to be free from defect for **90 days**. Does not apply to accident, misuse or normal wear & tear.



Additional Materials Needed:

- Galvanometer
- Direct current power source
1 1/2 volt dry cell with 10 to 20 ohm series resistor recommended. This resistor limits current flow to about 100 milliamperes, a low flow which eliminates likelihood of damage to galvanometer or other components.

- 6 short, heavy lead wires
- Set of resistance coils

We recommend 10-143 Set of 8 coils manufactured by Science First

Introduction:

The Wheatstone Bridge is a device that measures electrical resistance in a conductor by means of comparison, using a simple yet precise "bridge" circuit. Although invented by Christie in 1833, it is known as the Wheatstone Bridge after Sir Charles Wheatstone, a contemporary of Ohm, who popularized the concept.

The Wheatstone Bridge compares a wire with a known resistance to a wire with an unknown resistance to determine the resistance of the latter using a simple mathematical formula.

You need a galvanometer to indicate the exact spot at which current ceases to flow and the "bridge" is balanced. This therefore results in a visual demonstration of one application of **Ohm's Law**.

Product Description:

This apparatus is a *slide-wire Wheatstone Bridge*, so named because a contact key is slid along a straight length of wire and checked at short intervals until the desired position is reached. It consists of a rigid base containing a meter stick and series of terminals with **low resistance**. Two terminals at either end are connected to the meter stick by a low-resistance metal strip. Strung atop the meter stick is a nichrome wire of **high resistance**.

To use, you slide a slider with a tab at either end, a central terminal and two contact buttons along the meter stick. When you depress one of the buttons, you complete the electrical circuit at a point which can be accurately measured.

Two wire coils, one with **known** resistance, the other **unknown**, are connected to terminals at either end of the Wheatstone Bridge.

By connecting a **direct current power source** (1 1/2 volt dry cell) and a **galvanometer** (an instrument that measures small amounts of current), as described later, you can compute mathematically the resistance of the unknown wire using data derived at the point at which the galvanometer reads that no current is flowing.

How to Teach with Wheatstone Bridge

Concepts Taught: Electrical resistance, voltage and potential difference, current intensity, Ohm's Law, measurement of resistance, Wheatstone Bridge principle.

Curriculum Fit: PS/Electricity and Magnetism. *Unit: Electric Currents. Grades 11-12.*

Wheatstone Bridge as Electrical Scales:

One way to explain the operation of the Wheatstone Bridge is to imagine a balancing device similar to a pair of scales. An unknown quantity of a substance such as sugar is weighed on this pair of scales.

Place the sugar you are measuring on one side of the pair of scales; on the other, place a known weight of one, two, five or ten pounds. Start by approximating the weight of the unknown quantity of sugar as closely as possible. Add or take away small weights until the pair of scales is balanced. The Wheatstone Bridge measures electrical resistance in a similar fashion, by approximating, adding and subtracting resistances until the galvanometer reads zero and the "electrical scales" is balanced.

Theory: Bridge Analogy

The operation of the Wheatstone Bridge can be visualized as a stream of water (*Figure 1.*)

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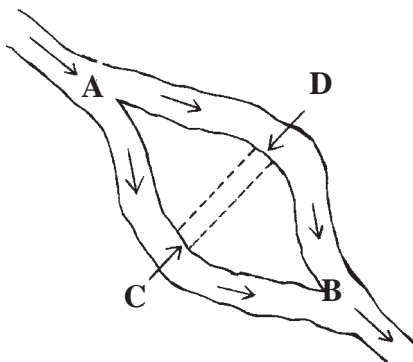


Figure 1

The stream divides at point **A**, forming an island, and reunites at **B**. **C** and **D** at opposite sides of the island represent a special case in which, if a ditch is dug between points **C** and **D**, there will be *no water flowing* through the ditch. This is because these points lie at exactly the same level. At this point the water pressure of the two streams is also the same - otherwise the water would flow toward the point with lower pressure.

The fall or difference in elevation of the two streams must be equal at the point where the ditch is dug. The fall of the stream from **A** to **C** equals that from **A** to **D**.

Since the streams rejoin at **B**, again a spot where the level of water pressure is identical for both streams, the fall from **D** to **B** is equal to the fall from **C** to **B**.

Figure 2 shows the electrical equivalent of the bridge analogy.

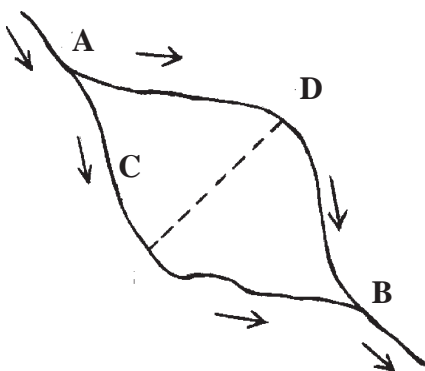


Figure 2

The electrical current divides - not necessarily equally - at **A** and reconnects at **B**. From any point **C** on one branch of the conductor, a corresponding point **D** exists in which no current flows between **C** and **D**. **C** and **D** therefore have the same electrical potential. The voltage drop, or

potential difference, from **A** to **C** equals that from **A** to **D**; the voltage drop from **C** to **B** equals that from **D** to **B**.

Figure 3 shows a typical Wheatstone Bridge electrical circuit.

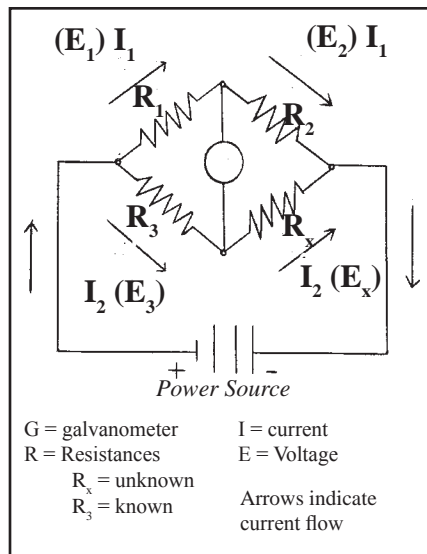


Figure 3

This circuit is a "bridge" because the parallel circuits **ACB** and **ADB** are linked by the circuit **CD** that connects the galvanometer **G**. When resistances are adjusted so that **C** and **D** are at the same potential, the bridge is considered balanced. This occurs when the galvanometer reads zero, because otherwise electrons would drift through the galvanometer and show a current still flowing.

R_1 , R_2 , R_3 and R_x indicate the various resistances at different parts of the Wheatstone Bridge circuit. R_3 and R_x are resistance coils connected to the Wheatstone Bridge; R_3 is known and R_x unknown. In Figure 3, R_1 and R_2 are lengths of the same piece of wire; in this case, a piece of nichrome wire of about 3 ohms total resistance, one meter in length (Figure 4.)

I_1 and I_2 are represented by arrows parallel to line segments **AC**, **CB**, **AD** and **DB**. They symbolize electrical current flowing through both branches of the bridge circuit.

Ohm's Law states that $E = IR$, where $E =$ voltage, $I =$ current and $R =$ Resistance. The fall of potential E is equal from **A** to **C** and from **A** to **D**. Therefore the current I_1 is the same from **A** to **C**

and from **C** to **B**. Since the bridge is balanced, there is no current flow from **C** to **D**. All current flowing from **A** to **C** must continue from **C** to **B** as no other pathway exists. Similarly, the current I_2 is the same from **A** to **D** and from **D** to **B**.

Therefore, $E_1 = E_3$ and $E_2 = E_x$.

Since $E = IR$,

$$R_1 I_1 = R_3 I_2 \quad \text{and} \quad (1)$$

$$R_2 I_1 = R_x I_2 \quad (2)$$

Dividing one equation by the other,

$$\frac{R_1 I_1}{R_2 I_1} = \frac{R_3 I_2}{R_x I_2} \quad \text{or}$$

$$\frac{R_1}{R_2} = \frac{R_3}{R_x} \quad (3)$$

Since the values of R_1 , R_2 and R_3 are known,

$$R_x = \frac{R_3 R_2}{R_1} \quad (4)$$

In this manner an unknown resistance can be measured by comparing it with 3 known resistances.

How To Use:

Refer to Figures 4 and 5. Figure 4 depicts electrical connections, represented by lines linking components. The direction of current flow is shown by arrows. Figure 5 labels other parts of the Wheatstone Bridge.

1. **Connect dry cell to 2 terminals at either end, points A and B** on the diagrams. They are electrically connected by means of a metal strip to a length of high resistance nichrome wire stretched on top of a meter stick. This wire is represented electrically as the circuit **ACB**. It is assumed to have uniform resistance.

2. **Connect galvanometer by means of two wires to points P and D**. **P** is a terminal in the middle of the slider. **C** is the point on the slider that contacts the wire at the point where the bridge is balanced; **C** can be moved by means of the slider. **D**, a fixed point, is a terminal located at the midpoint along the outer edge. This is the edge that does not contain the meter stick.

Connecting the direct current power source causes current to flow from **A** to **B** along the parallel circuits **ACB** and **ADB**.

3. **Choose two resistance coils, R_3 (known) and R_x (unknown), so that R_3**

is roughly similar to R_x . Connect these resistance coils to terminal pairs 1,2 and 3,4 at either end of Wheatstone Bridge with short, heavy lead wires. Terminals 1 through 4 are electrically connected to points A, D and B. **Tip: The instructor should try to balance the bridge in the vicinity of 50 cm.** This is to help prevent measurement errors.

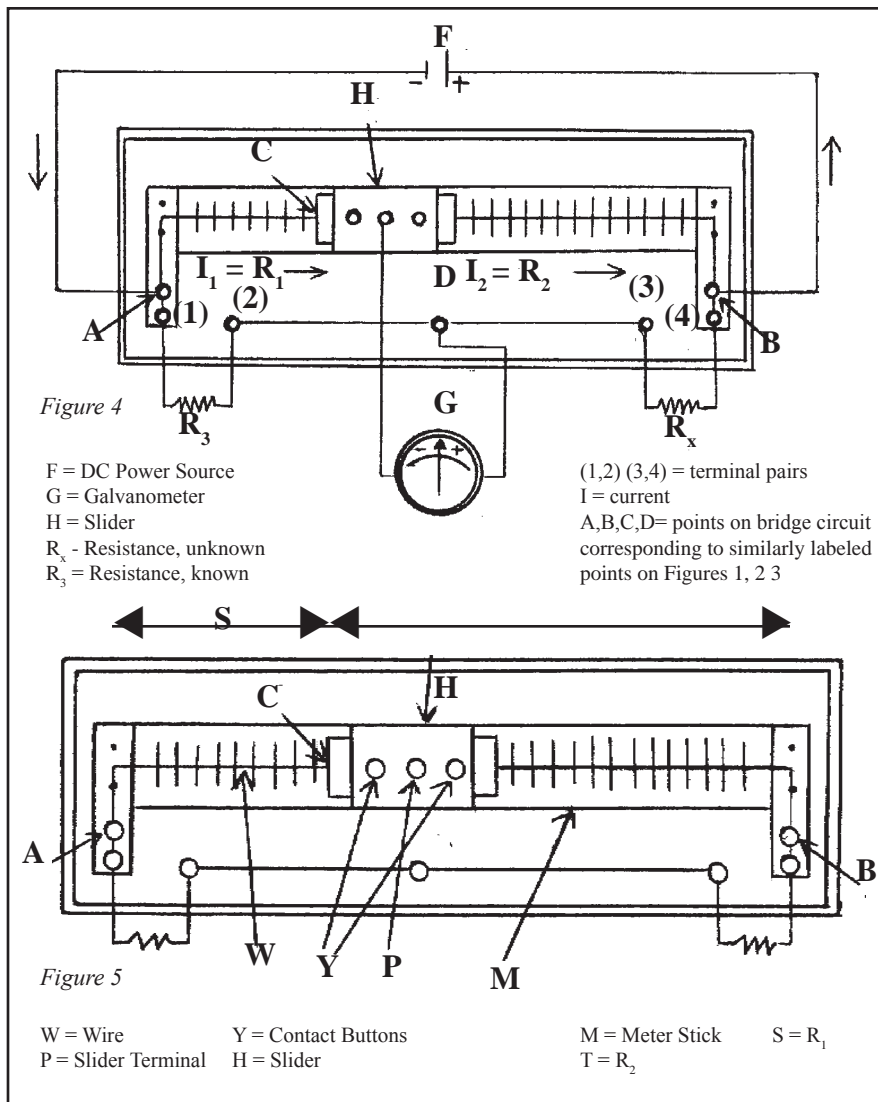
Values R_1 and R_2 are different lengths of the same piece of wire, specifically 2 segments of meter-long nichrome wire on either side of the slider, at whatever point the slider is positioned. R_1 will include all the resistance from point A to point C, including contact resistances and the resistance of the lead wires. R_2 will include all the resistance from C to B.

4. Position slider at about 50 cm. Tap one of contact buttons to check reading on the galvanometer. Handle the contact button lightly to safeguard the sensitivity of the galvanometer. Watch the direction in which the galvanometer tends to deflect rather than waiting for it to settle on a specific value, for the same reason.

5. Important! Protect the accuracy of your galvanometer by making sure the battery key is closed **before** the galvanometer key and opened **afterward**. Otherwise the needle on the galvanometer may slam and affect its reliability.

6. Move the slider a considerable distance. Tap the contact button again. Raise the contact button as you move the slider to prevent scraping off a portion of the slide wire. Observe the direction of deflection of the galvanometer key. If it is larger than the first time, move the slider in the opposite direction. Use the process of successive approximation, always with light taps on the contact button, until you obtain a reading near zero.

6. When near zero, use a move deliberate touch on the contact button to obtain a final reading on the galvanometer. When the galvanometer reads zero, the bridge circuit is balanced. **Record this position in cm on the meter stick.** If the known resistance, R_3 registers too close to either end, choose a larger or smaller resistance. The apparatus works best when values range near the midpoint of 50 cm. As in the analogy of weighing on scales, a letter would not be weighed on a bathroom scale.



7. Record values R_1 and R_2 . R_1 is the value indicated on the meter stick by the slider tab at the point where the galvanometer reads zero. Subtract this figure from the total length of the nichrome wire - 100 cm - to yield the value R_2 . For example, a measurement of 56.2 cm for R_1 , leaving 100 - 56.2, or 43.8, for R_2 .

8. Determine relationship between resistance and length of wire. Resistance, measured in ohms, is equated with specific lengths of wire, measured in centimeters. The relationship between the two is one of proportion depending on four factors:

- **Material** of which it is composed - in this case, nichrome
- **Length** of wire
- **Diameter** of wire
- **Temperature** of wire

Assumptions made: We assume the nichrome wire has uniform resistance along its entire length. We also assume all factors, except length, remain equal during each operation. The only factor that varies, therefore, is the length of the wire, which will be directly proportional to the resistance offered.

For example, a wire 20 feet long offers 4 times the resistance of a wire 5 feet long.

Figure 5 represents R_1 and R_2 by distances S and T. S is the length from A to C; T the length from C to B.

(The resistances of the contacts are much lower than that of the slide wire. It is assumed that the resistances of the electrical contacts between A and position 0 cm on the meter stick, and between B and position 100 cm on the meter stick, are so negligible as to equal zero.)

Since $S = R_1$ and $T = R_2$ and the values S and T are known values read in cm off the meter stick, the following formula calculates the unknown resistance:

$$R_x = \frac{R_3 S}{T} \quad (5)$$

In this example, where $R_1 = 56.2$ cm and $R_2 = 43.8$, assume R_3 (the known resistance coil) equals 8 ohms. Therefore,

$$\begin{aligned} R_x &= \frac{R_3 S}{T} \\ &= \frac{8 (56.2)}{43.8} \\ &= \frac{449.6}{43.8} \\ &= 10.26 \text{ ohms} \end{aligned}$$

In this manner the Wheatstone Bridge uses one known resistance coil, a meter stick, dry cell and galvanometer to determine the value of the second, unknown, resistance coil by means of comparison.

Measurement Errors:

It is important to minimize errors while using the Wheatstone Bridge. It is assumed in the procedure above that the contact resistances and resistance of lead wires approximate zero. This is primarily true if all resistances R_1 , R_2 , R_3 and R_x are large. If they are small, the resistances of the contacts and lead wires become increasingly important.

To reduce measurement errors when resistances are small:

1. Select an unknown resistance roughly similar to the known resistance and not too small to be easily measured.
2. If the point at which the bridge is balanced lies too close to either end of the meter stick, substitute the **next higher or lower resistance** until the point falls as near the center of the scale.
3. Make sure all contacts are good. Use large, heavy connecting wires. Check that all terminals are clean and tight.

One remedy for measurement errors is to interchange the known and unknown resistances and to average the values of the unknown resistance that result.

A similar procedure can also be used to minimize the errors inherent in the design of the Wheatstone Bridge. *Figure 6* illustrates where contact and line errors occur. Contact errors, which are those involving resistance in the terminal

connections, occur at points **E, F, G, H, I, J, K** and **Y**. These are points at which lead wires or metal conductors provide the necessary connections. Line errors involve resistance in wires and occur from **E to F, F to G, G to H, I to J** and **K to L**.

To correct for these various contact the line errors, the lead wire from the galvanometer (Z in *Figure 6*) can be connected to terminals other than the terminal in the midpoint of the meter stick. For example, connect lead Z to terminal **F**. Adjust slider until contact with the nichrome wire results in a zero reading on the galvanometer. Record on meter scale. For the purposes of this example, assume a value of 1.2 cm.

Repeat procedure by connecting lead wire Z to terminals **G, J** and **K**. The values obtained are:

$$\begin{aligned} F &= 1.2 \text{ cm} & G &= 43.8 \\ J &= 44.8 & K &= 98.4 \end{aligned}$$

Assume a known resistance R_3 of 8 ohms. Subtracting 1.2 from 43.8 results in the distance representing R_1 in the equation. Subtract 44.8 from 98.4 to obtain the distance representing R_2 .

Calculate R_x as follows:

Without corrections

$$\begin{aligned} R_x &= \frac{R_3 R_1}{R_2} \\ &= \frac{8 (100 - 43.8)}{43.8} \\ &= 10.26 \text{ ohms} \end{aligned}$$

With corrections

$$\begin{aligned} R_x &= R_3 \frac{(\text{relevant part of } S)}{(\text{relevant part of } T)} \\ &= \frac{8(98.4 - 44.8)}{(43.8 - 1.2)} \\ &= 10.07 \text{ ohms} \end{aligned}$$

The error in this example is not large, but if the unknown resistance R_x were small compared to the resistance of leads **I, J** and **L, K**, large relative errors would result.

Use the above procedure when determining the value of small unknown resistances.

Related Products:

These products may be ordered from most science distributors. For more information contact manufacturer **Science First**.

615-4500 Resistance Coils - 8 known resistances for use with Wheatstone Bridge. Each labeled coil has 2 brass terminals. Includes: 30 gauge nickel silver, 2 of 200 cm; 160 cm; 120 cm; 80 cm; 40 cm.

615-4545 Unknown Resistance - For use with Wheatstone Bridge. Assign different "unknowns" to lab groups. 9 precision 1% 1/4 watt resistors range from 1 to 100 kilohm. Each will survive up to 12 volts direct application.

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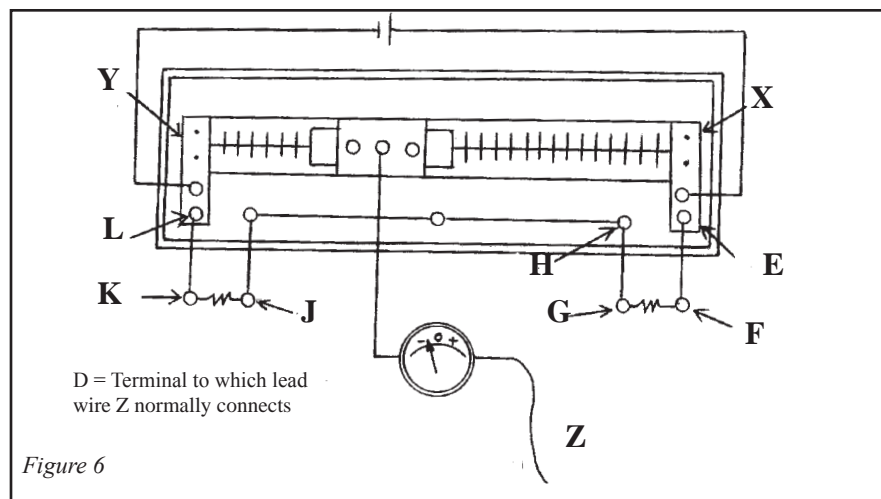


Figure 6