PHYSICS

Mercer University

Resistivity and Resistance

Physics Lab VII

Objective

In this set of experiments, the differences between resistance and resistivity will be explored.

Equipment List

A lump of Play – Doh©, four nails, a voltage supply, two multimeters, a flat piece of wood, ruler.

Theoretical Background

Most physical quantities of a material can be characterized as being either *intrinsic* or *extrinsic* properties. An intrinsic property is a property of a material that does not depend on the amount of material present. An extrinsic property, on the other hand, does depend upon the amount of material present. For example, all blocks of copper have the same density, since they are made of the same material, but different blocks can have different masses. Density is thus an intrinsic property. Mass, however, is an extrinsic property. A similar relationship exists between *resistance* and *resistivity* for an object when an electric current is passed through it. The resistivity, like the density, depends on the type of material. Every block of copper has the same resistivity. The resistance, like the mass, depends on how much of the material is present. The relationship between the resistance and the resistivity can be summed up by the following formula:

$$R = \frac{\rho \ell}{A}. \tag{1}$$

In this equation, R is the *resistance* of the object in question, ρ is the *resistivity* of the material the object is made of, ℓ is the length of the material, and A is the cross-sectional area the current flows through. If current flows through a cylindrical object, then the cross-sectional area of the cylinder is a circle; that is $A = \pi r^2 = \frac{\pi d^2}{4}$.

The current passing through the material and the voltage that is causing current to flow are related through the resistance (not the resistivity) by Ohm's Law as shown below:

$$V = IR. \tag{2}$$

In this equation, V is the potential difference (i.e. voltage) across the object, I is the current through the object, and R is the resistance of the object. In this lab, you will calculate the resistance of various lengths and cross-sectional pieces of Play – Doh© by measuring the voltage across and the current through the Play – Doh© , and from this resistance determine the resistivity.

Procedure

Length Dependence

1. Remove the Play – Doh© from its tin. Begin to work the Play – Doh© into a cylinder using your hands and the wooden slab. The shape should be uniform with a diameter approximately 2 *cm* and a length approximately 24 *cm*. It is not necessary to use all the Play – Doh© . Carefully use a caliper to measure the diameter at 5 places along the cylinder. Record each diameter measurement on your data sheet.

2. Take two of the nails and put them into the ends of the rolled out Play – Doh© .

3. *With the power supply turned off*, plug one end of a connecting wire (lead) into the power supply (the DC side). Select one multimeter and plug the other end of the lead into its **COM** terminal. Take another lead and run it from the **mA** terminal of the multimeter to one of the nails in the Play – Doh© . Take another lead and run it from the other nail in the Play – Doh© into the remaining terminal of the power supply.

4. Insert two more nails into the top of the Play – Doh© 18 cm apart. Measure and record the distance between the nails. Run a lead from one of the top nails to the **COM** terminal of the second multimeter. Run another lead from the other nail in the Play – Doh© to the **V** Ω terminal of the second multimeter.

5. Turn the dial of the multimeter that is connected to the power supply to the (**A**) current setting with a **200m** scaling factor. In this setting the displayed numbers on the multimeter will read in milliamperes. Turn the dial of the second multimeter to the (**V**) voltage setting with a scaling factor of **2**. In this setting, the second multimeter will read in volts.

6. *Turn both the* **Voltage Adjust** *knob and the* **Current Adjust** *knob to zero before turning on the power supply.* Turn the power supply on and turn the **Current Adjust** knob up a little. Next, turn the **Voltage Adjust** knob up until the current on multimeter reads 20 mA.

7. Record both the voltage and the current as shown on both multimeters.

8. *Turn down the voltage and current,* then remove one of the top nails from the Play – Doh© and move it 2 cm closer to the other top nail. Adjust the voltage from the power supply until the current on the multimeter reads 20 mA.

9. Record the new voltage, current, and distance between the nails.

10. Repeat steps 8 and 9 five more times to get a total of seven voltage/current measurements as a function of length.

Cross-Sectional Area Dependence

1. *Turn both the voltage and current knobs down to zero and turn off the power supply* and remove all of the nails from the Play – Doh© . Take the unused portion of Play – Doh© and combined it with the portion used previously. Reshape this larger lump into a cylinder, first with your hands and then with the wood slab. Roll the Play – Doh© lump down until it has a diameter of about 3.5 cm. Measure this diameter in five places and record these values on your data sheet.

2. Reconnect the nails as was done in the previous section. Place the two top nails 6 cm away from each other.

3. Turn the power supply on and first turn the current knob up a tad and then turn the voltage knob up until the current on the multimeter reads about 20 mA.

4. Record the voltage and current readings from the multimeters and the distance between the nails.

5. *Turn down the voltage and current,* then remove the top nails and roll the Play – Doh© out until its diameter has been reduced by about 0.5 cm. Measure the new diameter in five places and record these values on your data sheet.

6. Reinsert the top nails, again 6 cm away from each other. Turn the voltage and current back up until the current on the multimeter again reads 20 mA.

7. Record the voltage and current readings from the multimeters and the distance between the nails on your data sheet.

8. Repeat steps 5 through 7 three more times, to get a total of 5 voltage/current measurements for different diameters of the Play – Doh© .

9. Estimate the uncertainty in the length, diameter, voltage, and current measurement. From these values, and the smallest measured value of each quantity, determine the percent uncertainty in each. Record the largest value of the group as the largest percent uncertainty in the experiment.

$$\%\ uncertainty = 100 \times \frac{Uncertainty}{Smallest\ Measured\ Value} \tag{3}$$

Data Analysis

Length Dependence

1. Average the diameter measurements to get the mean diameter of each of the cylindrical
   Play – Doh© lumps and record this average diameter on your data sheet.

2. Calculate the average cross-sectional area using $A = \pi(d_{ave}/2)^2$.

3. Using equation 2, calculate the resistance of the Play – Doh© from each voltage/current measurement for each value of the distance between the nails, ℓ.

4. Calculate the resistivity of the Play – Doh© for each length measurement using equation 1. For A, use the average cross-sectional area calculated in step 2 of this section.

5. Calculate the average resistivity of the Play – Doh© and record it on your data sheet.

6. Calculate the percent variation in the resistivity and resistance. Record these values on your data table.

$$\%\ variation = 100 \times \frac{Largest\ Value\ -\ Smallest\ Value}{2 \times Average\ Value} \tag{4}$$

7. **Graph** the resistance, R, as a function of the distance between the top nails, ℓ. Fit a line of best fit to represent your data points. Calculate the slope of this line. Take the slope of this line and multiply it by the average cross-sectional area, A_{ave}. In your conclusion section, discuss how this value compares to the average resistivity you calculated previously.

Cross-Sectional Area Dependence

1. Average the distances between the nails, ℓ, and record this on your data sheet.

2. Calculate the resistance, R, for each diameter value from the voltage/current for that diameter.

3. Average the diameters and calculate the cross-sectional area for each diameter measurement using $A = \pi(d/2)^2$.

4. Calculate the resistivity for each cross-sectional area using equation 1 and record each value on your data sheet. In this calculation, for the length, ℓ use the average distance between the nails found in step 1 of this section.

5. Average the resistivity and resistance values and record these values on your data sheet.

6. **Graph** the resistance as a function of the inverse of the cross-sectional area (i.e. $1/A$). Fit a line of best fit to represent your data points. Take the slope of this line and divide it by the average distance between the nails, ℓ_{ave}. In your conclusion section, discuss how this value compares to the average resistivity you calculated previously.

Selected Questions

1. Examine your data from the **Length Dependence** procedure. Did the resistance vary significantly with length (length here is the distance between the top nails)? Did the resistivity vary with length? Theoretically, should the resistance have varied with length? Theoretically, should the resistivity have varied with length? Explain your reasoning.

2. Examine your data from the **Cross-Sectional Area Dependence** procedure. Did the resistance vary significantly with cross-sectional area? Did the resistivity vary with cross-sectional area? Theoretically, should the resistance have varied with cross-sectional area? Theoretically, should the resistivity have varied with cross-sectional area? Explain your reasoning.

3. As a current passes through an object, the object heats up. In this experiment, the heating process causes the Play – Doh© to dry out. How are both the resistance and resistivity affected by the heating process? Explain your reasoning.

4. Suppose a piece of wire is connected to a battery. If the wire is heated, its resistivity increases. How would this increase in resistivity effect the following quantities: the resistance of the wire, the voltage drop across the wire, and the current passing through the wire. Explain your reasoning.

5. Suppose a piece of wire is connected to a battery. A second piece of wire, made of the same material but longer than the first piece, is connected to a battery with the same voltage as the first battery. Indicate how each of the following quantities are affected by the second piece of wire being longer than the first: the resistivity, the resistance, the voltage drop across the wire, and the current through the wire.

6. Suppose a piece of wire is connected to a battery. A second piece of wire, made of the same material but thicker than the first piece (i.e. the second wire has a larger cross-sectional area than the first), is connected to a battery with the same voltage as the first battery. Indicate how each of the following quantities are affected by the second piece of wire being thicker than the first: the resistivity, the resistance, the voltage drop across the wire, and the current through the wire.