Ohm's Law and Resistivity

Your name_____   **Lab section**_____

1. What do you investigate in this lab?

2. When 1.0-A electric current flows through a piece of cylindrical copper wire, the voltage drop is 5.38 mV. What is the electric resistance of the wire?
    (Answer: $R=5.38\times10^{-3}$ V)

3. If the cylindrical copper wire has a diameter of 0.10 cm, calculate its cross-sectional area.
    (Answer: $A=7.85\times10^{-7}$ m^2)

4. If the cylindrical copper wire is 24 cm long, calculate its resistivity.
    (Answer: $\rho=1.76\times10^{-8}$ Ω·m)

Ohm's Law and Resistivity

Name_____   **Lab section**_____

Objective

In this lab, you investigate Ohm's law and measure the electric resistivity of metallic wires.

Background

Ohm's law is an empirical relationship between the voltage and the electric current for materials. For a piece of material, its resistance is defined as

$$R = \frac{V}{I},$$ (1)

where I (SI unit: ampere (A) =coulomb per second) is the current flowing through it and V (SI unit: volt (V)) is the voltage applied over it. The SI unit for resistance is: ohm (Ω).

For a piece of material, if its resistance is constant over a wide range of voltage (more accurately, over a wide range of electric field) such that

$$R = \frac{V}{I} \text{ is a constant,}$$ (2)

the material is described as ohmic and follow the empirical Ohm's law. Otherwise, it is called non-ohmic.

Most metallic materials such as brass, copper, and stainless steel are ohmic. For a piece of ohmic material, R, as the simple linear proportionality between V and I, is naturally an important parameter. R depends on the property and the specific shape and size of the material. For a wire of length L and uniform cross-sectional area A,

$$R = \rho \frac{L}{A},$$ (3)

where ρ is the resistivity of the material. Therefore, Ohm's law essentially states that the resistivity of an ohmic material is constant over a wide range of voltage (More accurately, over a wide range of electric field). **The SI units for Equation (3) are: ρ in ohm·meter (Ω·m); L in meter (m); A in square meter (m²); R in ohm (Ω).**

EXPERIMENT

Apparatus

Figure 1 displays the set-up used in this lab. DC power supply can output DC voltage 0−18 V with increment of 0.1 V. Connected a to-be-measured conducting wire in series with the variable resistor. **The resistance for latter can be set 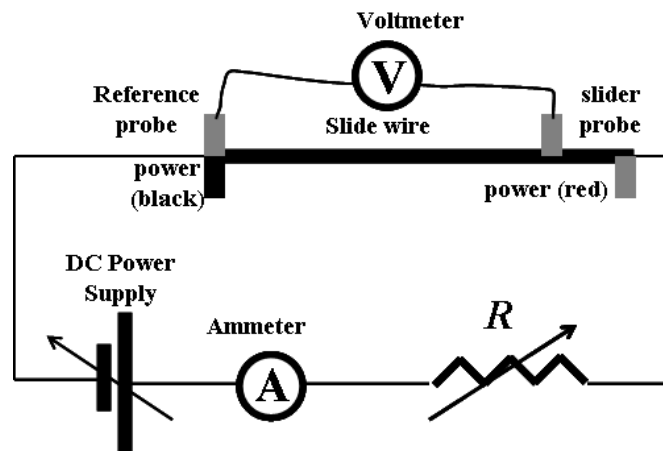at about 18.0 Ω**. **Caution: in this lab, always initially set the resistance of the variable resistor above 18.0 Ω and then slowly reduce it.**

Figure 1

To determine the resistance for a specific segment of the wire, the voltage across it is

measured by connecting the voltmeter **in parallel** with this wire segment, and the current flowing through it is measured by connecting the ammeter **in series** with it.

     <u>**Ohm's law**</u>   To demonstrate Ohm's law, measure several sets of the voltage drop across a stainless steel wire and the corresponding current through it. Plot *V*-versus-*I* and use Equation (2) to fit the curve.

     <u>**Resistance versus the length of the wire**</u>   Set the current through the stainless steel wire at 1.0 A. Measure the corresponding voltage across a segment of wire with length *l* decreasing from L_0 to 0. Plot (*V/I*)-versus-*l* and use Equation (3) to fit the curve. Use the obtained slope and the known cross-sectional area of the wire to calculate the resistivity.

     <u>**Resistance versus the cross-sectional area of the wire**</u>   Use four brass wires with different cross-sectional areas (*A*). Measure the resistances of all the wires. Plot (*V/I*)-versus-(*1/A*) and use Equation (3) to fit the curve.

Procedures

1. Set up the circuit (Figure 1)

     In this lab, two multi-meters are used. Use one as ammeter and the other as voltmeter. Initially set them at the appropriate sensitivity levels. Connect the positive lead of the power supply to the positive lead of the ammeter, and connect the ground of the ammeter to the end connector of the variable resistor. Move the slider connector of the variable resistor to make its resistance initially slightly above 18 Ω.

     The wire-slide apparatus has four connections. Connect the slider connector of the variable resistor to the positive power connector (red) of the wire-slide apparatus. Now, connect the negative power connector (black) of the wire-slide apparatus to the ground of the DC power supply. In so doing, *the ammeter is now connected in series with the to-be-measured wire*.

     Next, connect the positive lead of the voltmeter to *the slider probe* of the wire-slide apparatus and its ground lead to *the reference probe*. Thus, *the voltmeter is now connected in parallel with the to-be-measured wire*.

     At this moment, the power supply should remain turned off. **Ask your TA to check the circuit! Note: The wire-slider apparatus has a 2-A fuse. Do not run current over 1.5 A through it. Moreover, constant large current will heat up the wire and increase its resistivity.**

2. Install the stainless steel wire

     Slide the reference probe and the slider probe to their corresponding end positions, so they are parked on the ramps and do not hinder wire insertion. Loosen both wire clamps. The two alignment lines marked near the two wire clamps are used to guide wire insertion. Now, insert the dark gray stain-steel wire through the *front* of the left-hand clamp and through the *back* of the right-hand clamp. Tighten both clamps to secure the wire in place.

3. Ohm's law

     Move the reference probe of the wire-slider apparatus to the "0 cm" mark. Move the slider probe to the "24 cm" mark.

     Turn on the power supply. On the power supply, turn the voltage knob clockwise to the end. Then, turn the current knob clockwise very slowly, until the ammeter reads at 1.0 A. If the reading is still below 1.0 A even when the current knob is turned clockwise to the end, slowly reduce the resistance in the variable resistor (ask your TA how to do this) until you read 1.0 A.

     When the ammeter reads at 1.00 A, record the voltage across the wire measured by the voltmeter in Table 1. Next, turn the voltage knob counter-clockwise to set the current (measured by the ammeter) in turn to 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1 A, read the corresponding voltages across the wire on the voltmeter (note: the voltage reading on the voltmeter may use the unit of mV) and record the data in Table 1.

TABLE 1   The 24-cm-Long Stainless-steel Wire

I (A)	V (mV)	I (A)	V (mV)
1.00		0.50	
0.90		0.40	
0.80		0.30	
0.70		0.20	
0.60		0.10	

4. Resistance-versus-length for the brass wire of 0.040 in diameter

Turn off the power supply. Move the reference probe and the slider probe of the wire-slider apparatus to their corresponding end positions. Loosen the clamp and remove the stainless-steel wire. Following step 2, install the brass wire (yellow) of diameter D=0.040 in (the second thickest brass wire). Move the reference probe of the wire-slide apparatus to the "0 cm" mark, and move the slider probe initially to the "24 cm" mark.

Turn on the power supply. <u>Follow the procedures described in step 3 to **set the current measured by the ammeter to 1.0 A**</u>. Read the voltage across the wire segment using the voltmeter and record in Table 2. Next, move the slider probe of the wire-slide apparatus in turn to the 20, 16, 12, 8, 4-cm mark (note: the current reading on the ammeter should not change), measure the corresponding voltages across the wire segment using the voltmeter and record in Table 2. Calculate the corresponding resistance for each case.

TABLE 2   The diameter D=0.040 in Brass Wire

l (cm)	I (A)	V (mV)	R (Ω)
24	1.0		
20	1.0		
16	1.0		
12	1.0		
8	1.0		
4	1.0		

5. Resistance-versus-diameter for the brass wires of different diameters

Repeat the above measurement in turn for the brass wires with diameters D=0.050, 0.032, and 0.020 in, set **the length at l=24 cm and I=1.0 A**. Record the corresponding voltages in Tables 3.

TABLE 3   The 24-cm-Long Brass Wires

D (in)	I (A)	V (mV)	R (Ω)	A (m²)	1/A (m⁻²)
0.050	1.0				
0.040	1.0				
0.032	1.0				
0.020	1.0				

Analysis
1. The 24-cm-long stainless-steel wire

Use the data in Table 1, plot the *V*-versus-*I* curve. Use Equation (2) to fit the curve and determine the resistance   *R*=

The diameter of the wire is D=0.040 in. Calculate the cross-sectional area (1 inch = 2.54 cm) $A = \pi D^2 / 4$. Use Equation (3) to calculate the resistivity:

$\rho=$

2. Four brass wires

For each wire, calculate the cross-sectional area (1 inch = 2.54 cm) $A = \pi D^2 / 4$ and record the A values in Tables 3 and 4. For the brass wire of 0.040-in diameter, plot the R-versus-l curve and use Equation (3) to fit the curve and record the R/l slope in Table 4, use the obtained slope and Equation (3) to calculate the resistivity of brass and record it in Table 4.

TABLE 4   0.040-In-Dimater Brass Wire

D (in)	slope (Ω/m)	A (m²)	ρ (Ω·m)
0.040			

For each wire, calculate its resistance at 24 cm and calculate the l/A value. Record them in Tables 3. Plot the R-versus-l/A curve. Record the RA slope in Table 5, use the obtained slope and Equation (3) to calculate the resistivity of brass and record it in Table 5.

TABLE 5   Four Brass Wires

slope (Ω·m²)	l (m)	ρ (Ω·m)
	0.24	

Questions

1.   Does the measured V-versus-I curve for the stainless-steel wire follow Ohm's law?

2.   Based on the measurements on the four brass wires, what relationships can you draw for R−versus−l and R−versus−A?

3.   If a brass wire is 4 cm long with a diameter of 1.3 cm, can you use the set-up in this lab to measure its resistance? (Hint: consider the limitation of sensitivity for measuring voltage.)
(Answer: No. The voltage over the wire is 0.022 mV at 1.0 A and only 0.044 mV even at 2.0 A!)