General Physics Lab 2

Resistors

Objectives:

- To explore what quantities affect resistance
- To study resistors in series and parallel combinations

Equipment:

- Multimeter with Probes
- Breadboard
- 1 kΩ Resistor (brown, black, red, gold)
- 2 kΩ Resistor (red, black, red, gold)
- 3 kΩ Resistor (orange, black, red, gold)
- Conductive Paper (1 sheet for each part)
- Conductive Tape (part 1 – 11 cm, part 2 – 56 cm)
- Scissors

Physical Principles:

Physical Parameters Determining Resistance

The amount of resistance depends on a few physical parameters of the resistor. It is directly proportional to the length, L, of the resistor, inversely proportional to the cross sectional area, A, and also depends on the type of material, ρ (resistivity), the current must flow through. These relationships appear as

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

Increasing the length of a resistor increases the resistance.
Increasing the cross sectional area of a resistor decreases the resistance.

Combinations of Resistors

Resistors may be combined as either series or parallel combinations (see Fig. 1).

In series (Fig. 1a), the equivalent resistance is

$$R_{eq} = R_1 + R_2 + R_3 + \cdots + R_n \ . \qquad \text{(series)} \qquad (2)$$

Adding resistors in series is analogous to increasing the length of the equivalent resistance. More resistors in series increases the equivalent resistance.

In parallel (Fig. 1b), the equivalent resistance is

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n} \ . \qquad \text{(parallel)} \qquad (3)$$

Adding additional resistors in parallel is analogous to increasing the cross sectional area of the equivalent resistance. More resistors in parallel decreases the overall equivalent resistance.

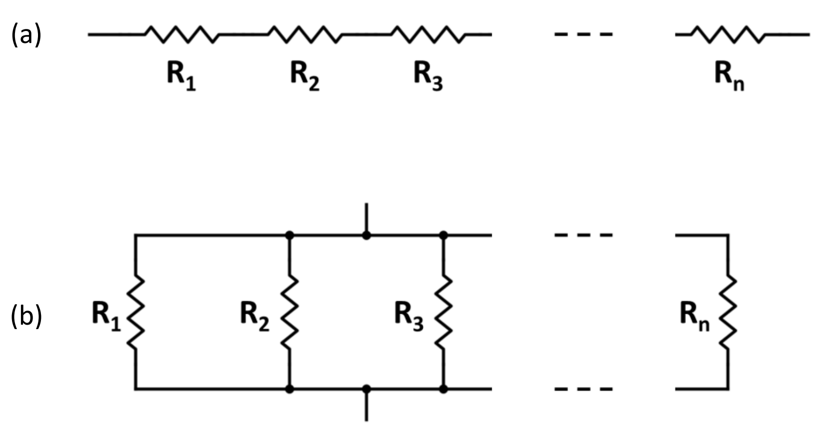

Fig. 1: Resistors combined in (a) series and (b) parallel

Note: One lab partner must complete Part 1 and the other partner must complete Part 2. All parts must be completed.

Procedure (Part 1):
Resistance and Length

Setup

1. Cut a 1 cm wide strip of conductive paper as shown in Fig. 2. Make sure to include the top and bottom margins as shown below.

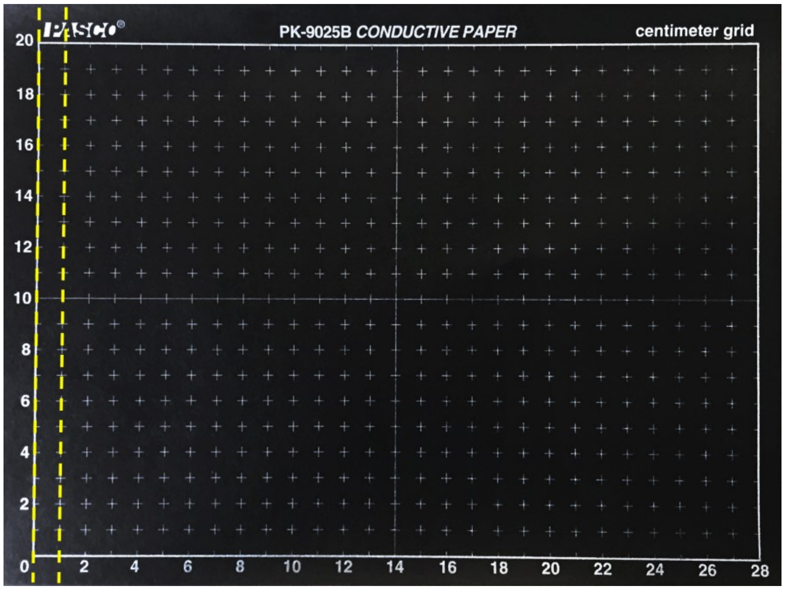

Fig. 2: Cut a 1 cm wide strip of conductive paper as shown by the dashed yellow lines.

2. Cut 11 pieces of conductive tape the same width as the conductive paper strip (1 cm). Do not remove the paper backing from the tape yet.
3. Take 2 of the conductive tape pieces and apply one at each end of the conductive paper with the edge of the tape strips aligned at the top and bottom of the grid. Their edges should be separated by 20 cm (see Fig. 3).

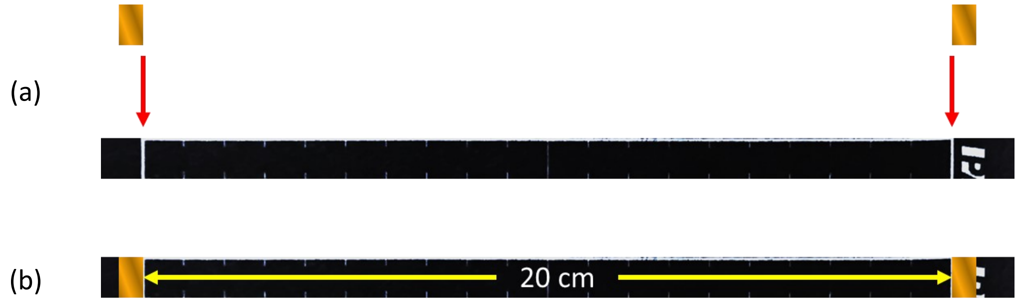

Fig. 3: (a) Apply a piece of conductive tape to each end of the conductive paper strip. (b) The two tape pieces should be separated by 20 cm.

Measure Resistance of Conductive Paper with Varying Length

1. Turn the multimeter dial to measure ohms (Ω) and set it to the lowest range that will give a value. This will most likely be the 200k range.
2. Insert the black probe into the common (COM) port and the red probe into the port for resistance (Ω).
3. Measure the resistance of the conductive paper strip by placing one probe at each end, point down on the conductive tape (see Fig. 4).
   Record the resistance, R, and length, L (20 cm).

   Note: The resistance will vary slightly depending on where you place the probe tips. To minimize any error from this, try to place the multimeter probe tips in the same place on the conductive tape strips for each resistance measurement. In Fig. 4, the edge of the conductive tape was selected as the measurement point.

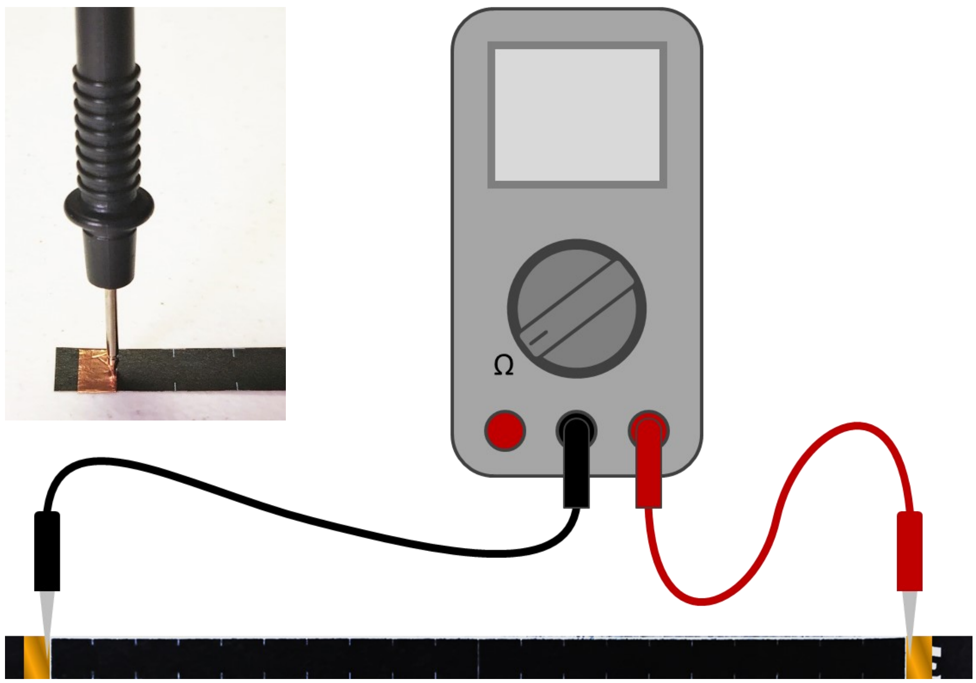

Fig. 4: Measure the resistance of the conductive paper strip by pressing the multimeter probe tips into the conductive tape at each end of the paper strip.

4. Now apply another strip of conductive tape to the conductive paper 2 cm closer to the other end. Now the distance between the two conductive tape strips should be 18 cm (see Fig. 5a).
5. Cut the conductive paper between the new tape strip and the old one (see Fig. 5b & c). Leaving this connected would alter the resistance of the conductive paper so it must be removed before the next measurement.

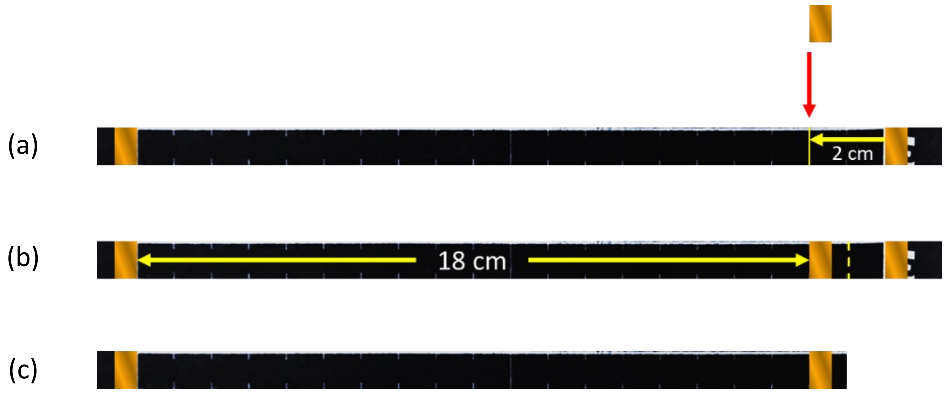

Fig. 5: (a) Apply another piece of conductive tape 2 cm over so that the new length between conductive tape strips is 18 cm. (b, c) Cut the paper between the new and old tape strips (dashed line) to make a shorter paper strip with an 18 cm separation between the pieces of conductive tape.

6. Measure and record the new resistance, R, and length, L, of the 18 cm strip. Again, try to place the multimeter probe tips in the same place on the conductive tape as before.
7. Continue this process of adding a strip of conductive tape 2 cm over from the previous location, cutting off the extra paper with the previous tape strip, and measuring the new resistance. Each time record the resistance, R, and length, L. Continue until you have measured a 2 cm long strip of conductive paper (see Fig. 6).

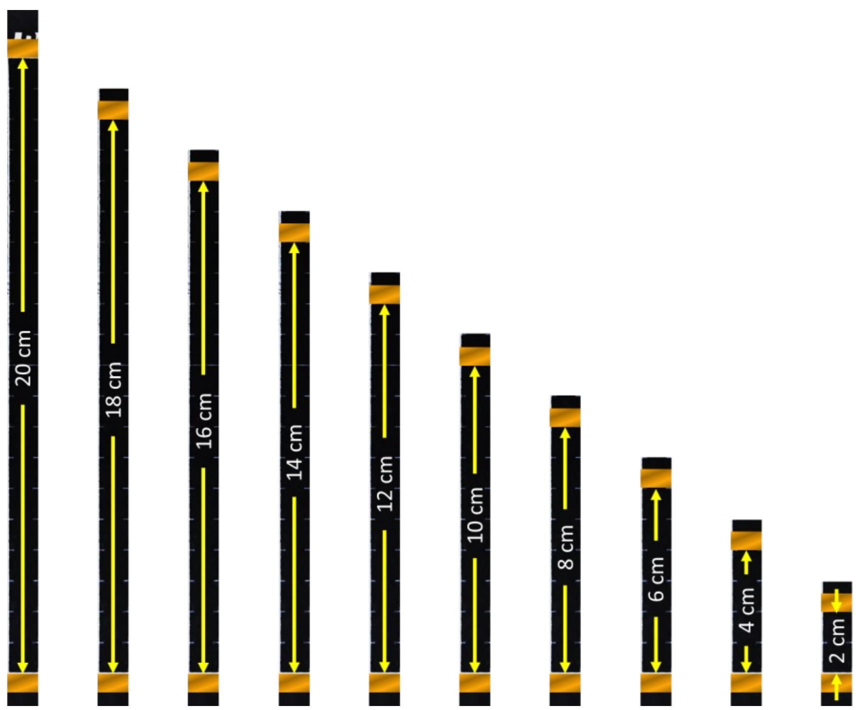

Fig. 6: Measure the resistance of the conductive paper strip for lengths of 20 cm, 18 cm, 16 cm, … 2 cm.

Measure Resistance of Series Resistors

1. Locate the 1 kΩ, 2 kΩ, and 3 kΩ resistors from your lab kit.

   You can tell the resistor's nominal value from the 4 or 5-band color code printed on the resistor. To interpret this code, look up a resistor color code table or use an online calculator such as this one: https://resistorcolorcodecalc.com/.

2. One at a time, carefully (it is easy to bend the resistor leads and hard to re-straighten them) place the 1 kΩ, 2 kΩ, and 3 kΩ resistors in the breadboard and measure the individual resistances (see Fig. 7a). Set the multimeter dial to the lowest (most accurate) range that still gives a value.
3. Place the three resistors in series and measure the equivalent resistance (see Fig. 7b). In order for the resistors to be in series, the connected resistor leads must be in the same row of 5 holes.

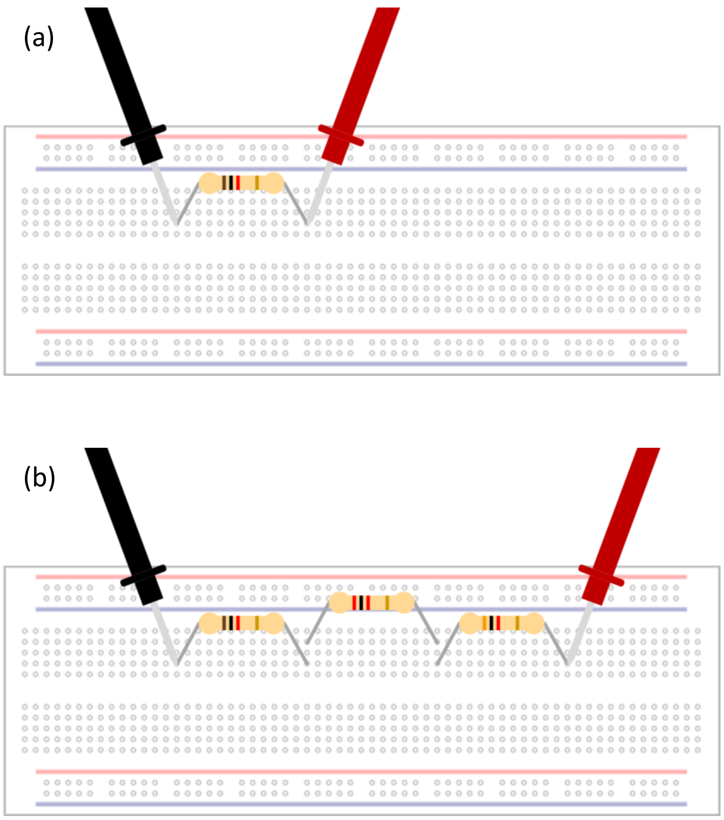

Fig. 7: (a) Carefully place each resistor in the breadboard as shown and measure the individual resistance of each. (b) Place all three resistors in series and measure the total equivalent resistance across all three. Make sure that where the resistors connect to each other, they each have a lead in the same row of 5 holes. If they are not in the same row, they are not connected.

IMPORTANT: When you finish the experiment, turn off the multimeter to save the battery. The simpler inexpensive multimeters often do not shut off automatically.

Analysis (Part 1):

Conductive Paper Resistance

Plot R (y-axis) vs. L (x-axis) and perform a linear fit, using Graphical Analysis or a spreadsheet program. Include the point (0,0) corresponding to the fact that a resistor of zero length will have zero resistance. Record the correlation coefficient (also called R) to determine the linearity of your data and to check the validity of Eq. (1).

Recall that a correlation coefficient of +1 is a perfect positive correlation, -1 is a perfect negative correlation, and 0 is no correlation.

Series Resistance

Use a percent difference to compare the measured resistor values to their nominal resistance.

$$\%Diff = \frac{|Nominal - Measured|}{Nominal} \times 100\%$$

Are these percent differences within the tolerance for your resistors?

Common Tolerance Colors: Silver band = ±10%, Gold band = ±5%, Brown band = ±1%
Check a resistor color code table if your resistors have a different tolerance.

Use a percent difference to compare the measured equivalent series resistance with the prediction of Eq. (2).
Use the measured individual resistances (not the nominal values) when calculating the predicted series resistance.

$$\%Diff = \frac{|Predicted - Measured|}{Predicted} \times 100\%$$

Procedure (Part 2):
Resistance and Area

Setup

1. Cut a sheet of conductive paper into 7 strips (not counting the left and right margins) with widths of 1, 2, 3, 4, 5, 6, and 7 cm (see Fig. 8). Include the top and bottom margins on each strip as shown below.

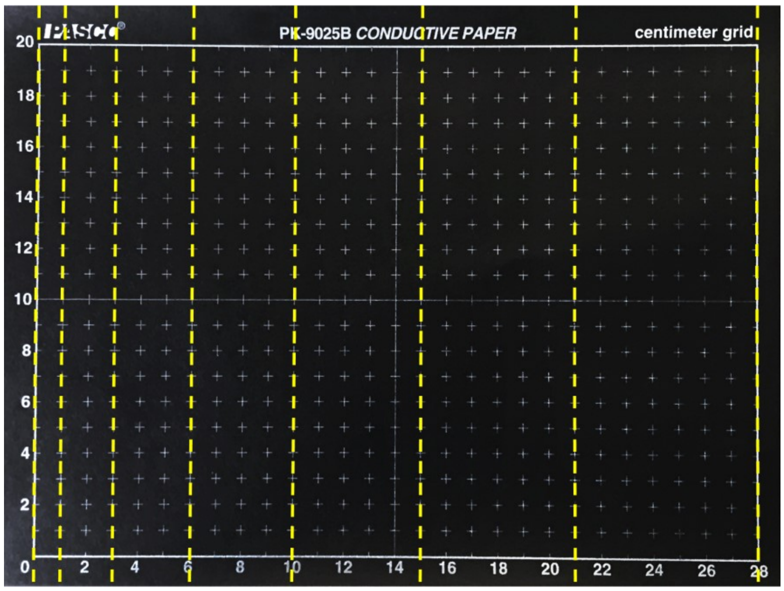

Fig. 8: Cut a sheet of conductive paper into 7 strips with widths of 1, 2, 3, 4, 5, 6, and 7 cm.

2. Cut strips of conductive tape the same width as each conductive paper strip so that you have 2 pieces of conductive tape for each strip of paper (one for each end).
   Do not remove the paper backing from the tape yet.
3. Apply one piece of conductive tape to each end of the conductive paper strips, with the edge of the tape strips aligned to the top and bottom of the grid. They should be separated by 20 cm (see Fig. 9).

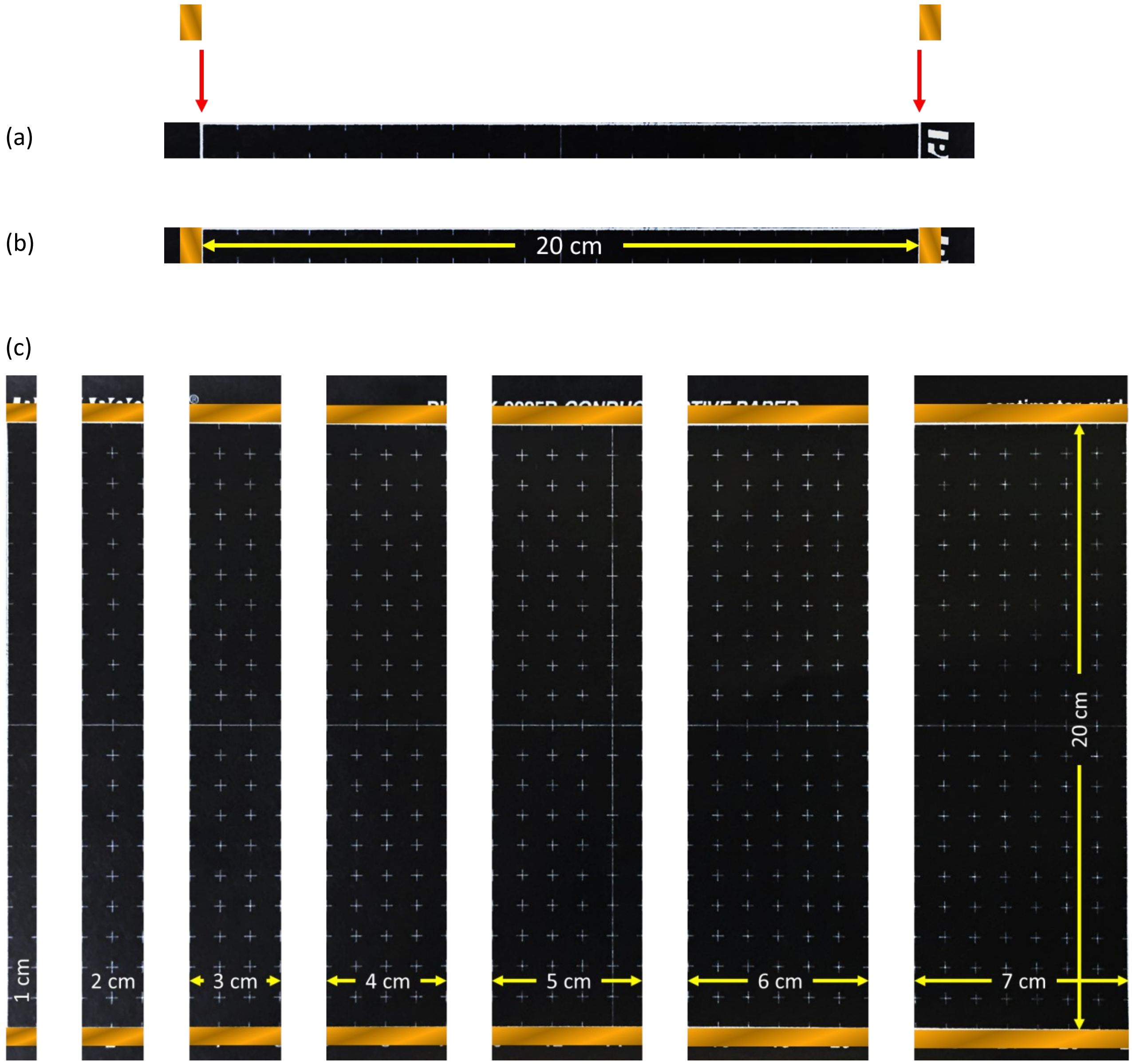

Fig. 9: (a) Apply a piece of conductive tape to each end of the conductive paper strips. (b) The two tape pieces should be separated by 20 cm. (c) When finished with this step, you should have 7 strips of conductive paper with conductive tape on each end.

Measure Resistance of Conductive Paper with Varying Width

1. Turn the multimeter dial to measure ohms (Ω) and set it to the lowest range that will give a value. This will most likely be the 200k range.
2. Insert the black probe into the common (COM) port and the red probe into the port for resistance (Ω).
3. Measure the resistance of each conductive paper strip by placing one probe at each end, point down on the conductive tape (see Fig. 10). Record the resistance, R, and width, w, for each strip.

   Note: The resistance will vary slightly depending on where you place the probe tips. To minimize any error from this, try to place the multimeter probe tips in the same place on the conductive tape strips for each resistance measurement. In Fig. 10, the edge of the conductive tape was selected as the measurement point.

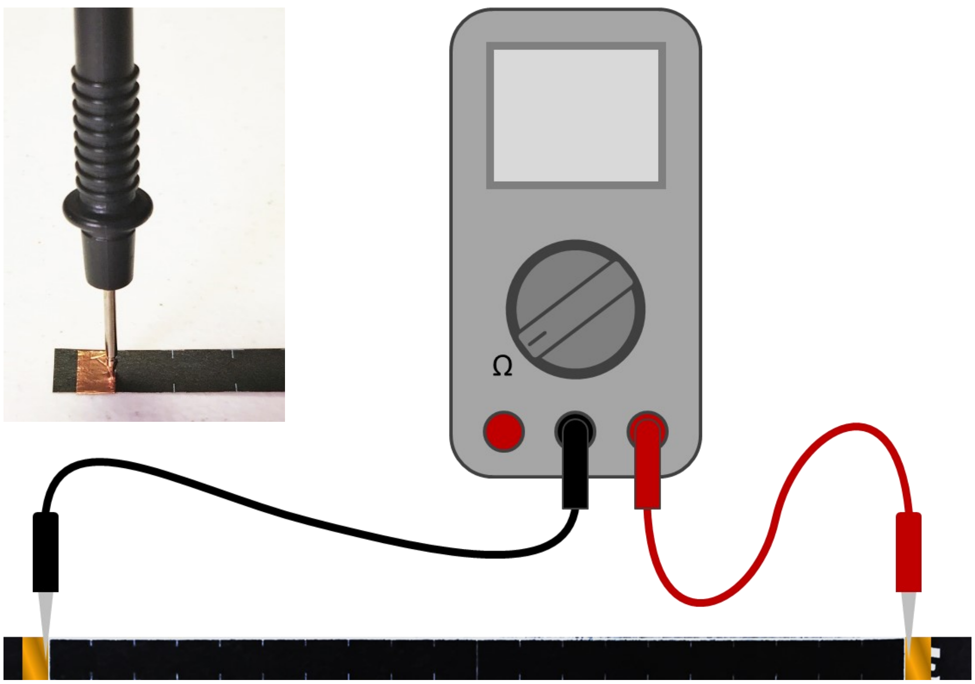

Fig. 10: Measure the resistance of each conductive paper strip by pressing the multimeter probe tips into the conductive tape at each end of the paper strips.

Measure Resistance of Parallel Resistors

1. Locate the 1 kΩ, 2 kΩ, and 3 kΩ resistors from your lab kit.

   You can tell the resistor's nominal value from the 4 or 5-band color code printed on the resistor. To interpret this code, look up a resistor color code table or use an online calculator such as this one: https://resistorcolorcodecalc.com/.

2. One at a time, carefully (it is easy to bend the resistor leads and hard to re-straighten them) place the 1 kΩ, 2 kΩ, and 3 kΩ resistors in the breadboard and measure the individual resistances (see Fig. 11a). Set the multimeter dial to the lowest (most accurate) range that still gives a value.
3. Place the three resistors in parallel and measure the equivalent resistance (see Fig. 11b). In order for the resistors to be in parallel, the connected resistor leads must be in the same row of 5 holes.

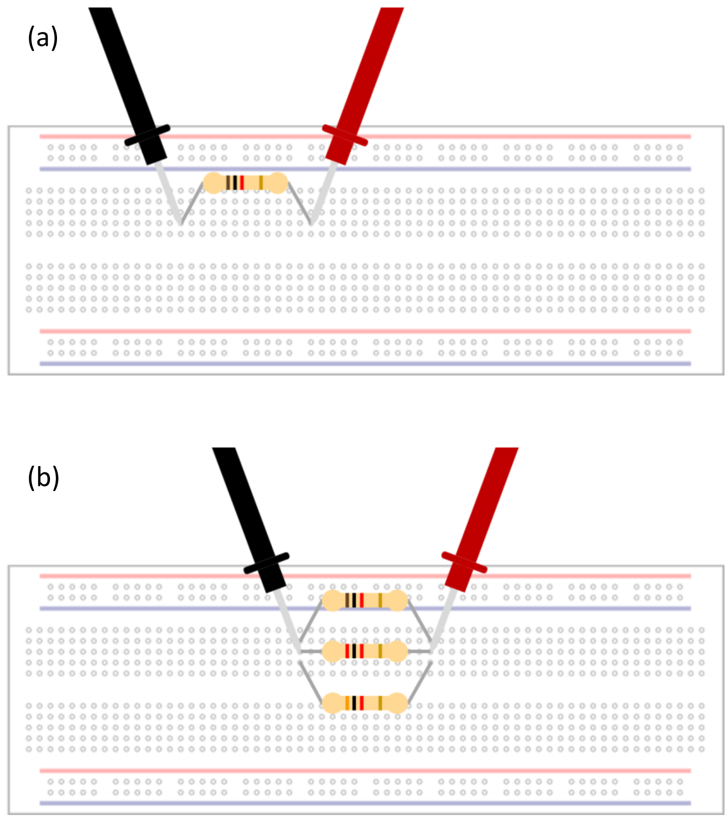

Fig. 11: (a) Carefully place each resistor in the breadboard as shown and measure the individual resistance of each. (b) Place all three resistors in parallel and measure the total equivalent resistance across all three. Make sure that where the three resistor leads connect to each other, they are all in the same row of 5 holes. If they are not in the same row, they are not connected.

IMPORTANT: When you finish the experiment, turn off the multimeter to save the battery. The simpler inexpensive multimeters often do not shut off automatically.

Analysis (Part 2):

Conductive Paper Resistance

Considering the rectangular cross section of a sheet of paper of width, w, and constant thickness, t,

$$Area = thickness \times width = t \cdot w \ . \qquad (4)$$

Thus, according to Eq. (1), resistance is inversely proportional to width.

$$R \propto \frac{1}{A} \propto \frac{1}{w}$$

Plot R (y-axis) vs. 1/w (x-axis) and perform a linear fit, using Graphical Analysis or a spreadsheet program. Record the correlation coefficient (also called R) to determine the linearity of your data and to check the validity of Eq. (1).

Recall that a correlation coefficient of +1 is a perfect positive correlation, -1 is a perfect negative correlation, and 0 is no correlation.

Parallel Resistance

Use a percent difference to compare the measured resistor values to their nominal resistance.

$$\%Diff = \frac{|Nominal - Measured|}{Nominal} \times 100\%$$

Are these percent differences within the tolerance for your resistors?

Common Tolerance Colors: Silver band = ±10%, Gold band = ±5%, Brown band = ±1%
Check a resistor color code table if your resistors have a different tolerance.

Use a percent difference to compare the measured equivalent parallel resistance with the prediction of Eq. (3).
Use the measured individual resistances (not the nominal values) when calculating the predicted parallel resistance.

$$\%Diff = \frac{|Predicted - Measured|}{Predicted} \times 100\%$$