General Physics Lab 1

Electric Field Mapping

Objectives:

- To determine the lines of constant potential and map the electric fields produced by various arrangements of charged conductors

Equipment:

- Multimeter with Probes
- 9V Battery
- 9V Battery Connector
- 3 Alligator Clip Wires
- Conductive Paper (1 sheet for each part)
- Conductive Tape (part 1 – 24 cm, part 2 – 6 cm)
- China Markers (red and yellow)
- Scissors
- Ruler
- Tape

Physical Principles:

Electric Field

We define the electric field, $\vec{E}$, at a point in space to be the force per unit charge that a test charge, q', would experience if placed at that point, i.e.,

$$\vec{E} = \frac{\vec{F}}{q'} \quad (1)$$

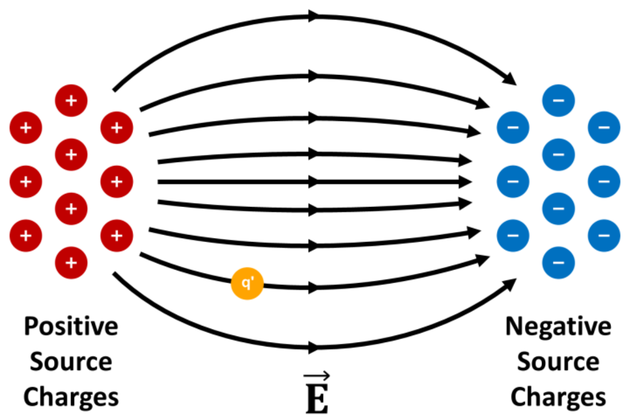


Fig. 1: Place a test charge, q', in an electric field, E, and it experiences a force, $\vec{F} = q'\vec{E}$.

The force (and field) are produced by various distributions of surrounding source charges (see Fig. 1). Units of force are Newtons (N) and units of charge are Coulombs (C), thus, the units of electric field are Newtons/Coulomb (N/C). The direction of the electric field (vector) is in the same direction as the force on a positive test charge.

Electric Potential (Voltage)

We define electric potential, V, at a point in space to be the electrical potential energy per unit charge that a test charge, q', would have if placed at that point:

$$V = \frac{U_E}{q'} , \qquad (2)$$

where U_E , is electrical potential energy and q', is the amount of test charge. U_E has SI units of Joules (J), q' has units of Coulombs (C) and V has units of volts (V) where 1 V = 1 J/C.

Equipotential lines (equivoltage lines) are lines drawn on a two-dimensional surface where the potential difference between any two points along the same line is zero. They are lines of constant potential and constant potential energy for charges, q'. No work is required to move a charge along an equipotential line. These lines are analogous to the lines of constant altitude on a topographical map where travel along the line does not involve movement either uphill or downhill and requires no work.

Along equipotential lines both the electric potential (voltage), V, and for a charge, q', the electrical potential energy, U_E are constant.

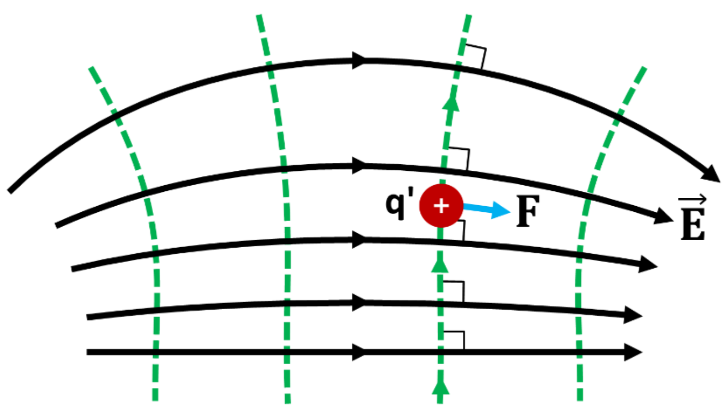


Fig. 2: The electric field does no work on a charge q' that moves along an equipotential path perpendicular to the field.

The electric field lines and the equipotential lines are related to one another, but with two major differences.

1. Electric field lines are always perpendicular to the equipotential lines (see Fig. 2).
2. Electric field lines are vectors while equipotential lines are not.

Since a constant electrical force is related to work done on a charge or change in potential energy by the relation,

$$F = \frac{W}{d} = \frac{\Delta U_E}{d} \ , \tag{3}$$

where d is the displacement of the charge.

A similar relation exists between a constant electric field (F/q') and electric potential (U_E/q') as shown in Eq. (4) and Fig. 3.

$$E = \Delta V / d \ . \tag{4}$$

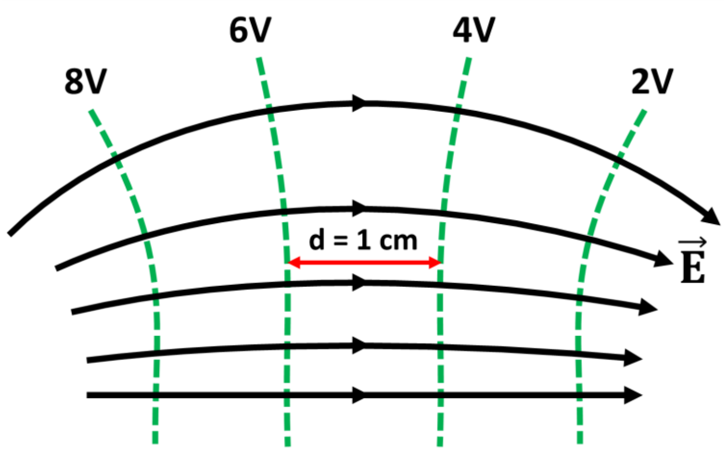


Fig. 3: A voltage difference of 2 V over a distance of 0.01 m corresponds to E = 2/0.01 = 200 V/m.

Equipotential and electric field lines for parallel plates and an electric dipole appear as in Fig. 4.

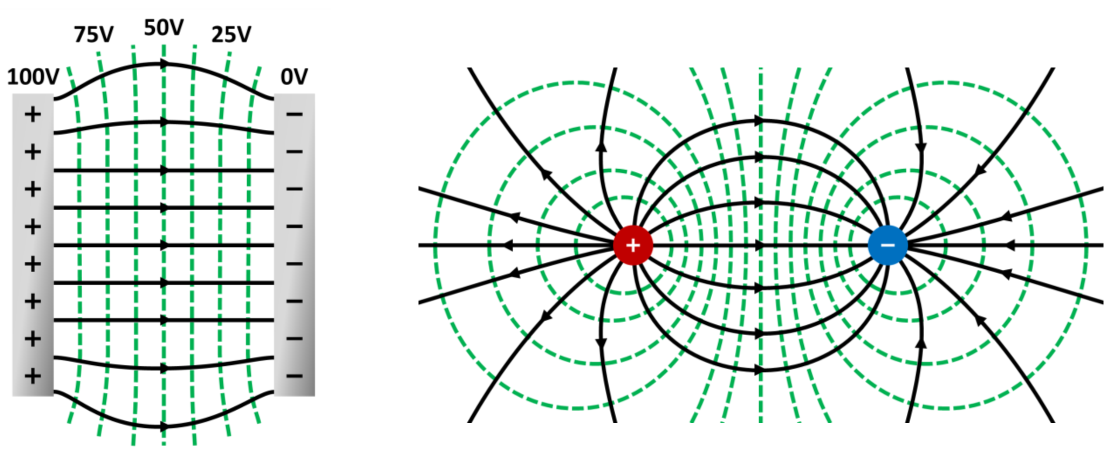


Fig. 4: Equipotential lines and electric fields in the vicinity of (a) parallel plates of charge and (b) an electric dipole.

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

Procedure (Part 1):

Parallel Conductors

This experiment will involve plotting equipotential lines and electric field lines generated by two parallel lines with a potential difference between them. This particular arrangement is useful because it simulates the nearly-uniform field between the parallel charged plates of a capacitor.

Setup

1. Cut two 12-cm-lengths of conductive tape.
2. In the center of each strip of conductive tape, Fold an approximately 1 cm fold near the center of each strip of tape to act as a tab for alligator clips to connect with (see Fig. 5). The fold in the center should be 1 cm on each side, using 2 cm of the 12 cm length.

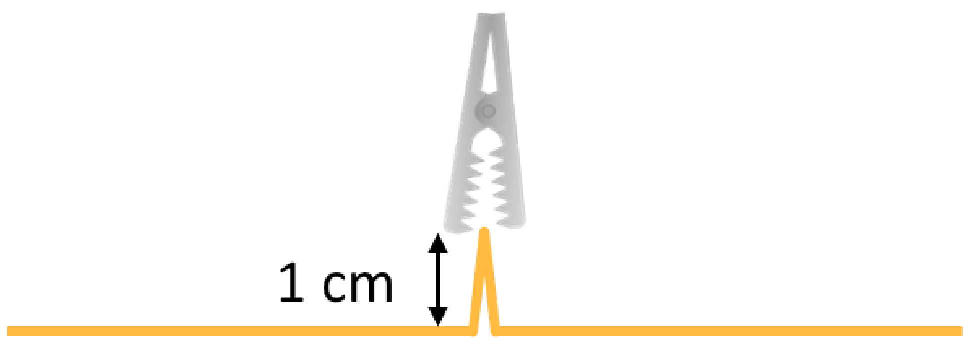


Fig. 5: Conductive tape with tab for alligator clip contact.

3. Carefully apply one strip of conductive tape to the conductive paper stretching from the point (7,5) to (7,15) with the tab on the center line (see Fig. 6a). Take extra care to place it correctly the first time. If you try to remove the tape, it will probably tear the paper.
4. Apply the second strip parallel to the first from point (21,5) to (21,15). Again, the tab should be on the center line. After this, you should have two parallel lines of conducting tape separated by 14 cm (see Fig. 6b).

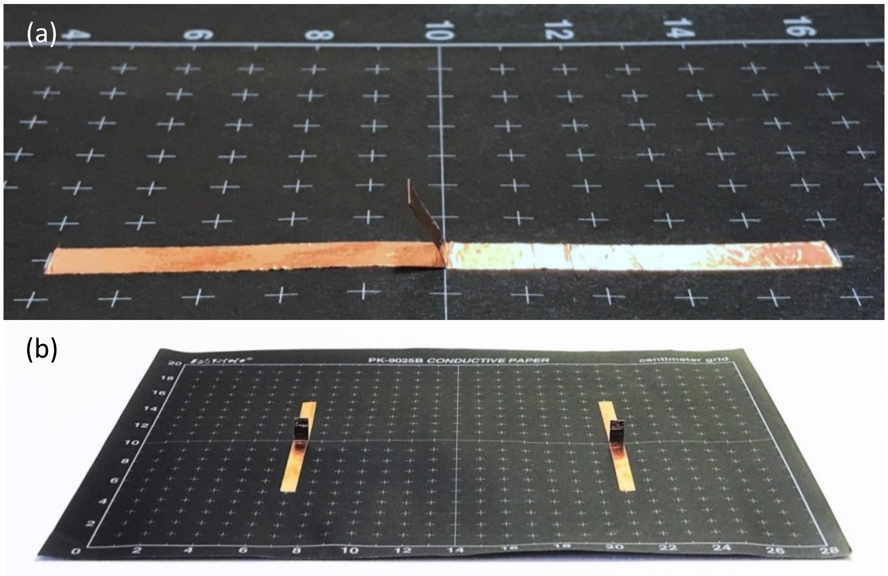


Fig. 6: (a) 12-cm strip of conductive tape carefully applied to the conductive paper with a tab on the center line. (b) Two parallel strips of conductive tape applied to the conductive paper. Left strip applied between points (7,5) and (7,15). Right strip applied between points (21,5) and (21,15).

5. Snap the battery connector onto the battery.
6. Use an alligator clip wire (wire with alligator clip on each end) to connect the positive pole of the battery (anode – red battery connector wire) to one strip of the conductive tape. You can choose which side you want to connect it to.
7. Use a second alligator clip wire to connect the negative pole of the battery (cathode – black battery connector wire) to the other strip of conductive tape.
8. Arrange the alligator clips so that they lie flat on their insulating rubber and do not stress the conductive tape tabs. Electrical tape may be useful to secure the wires and hold everything down to the table. See Fig. 7.

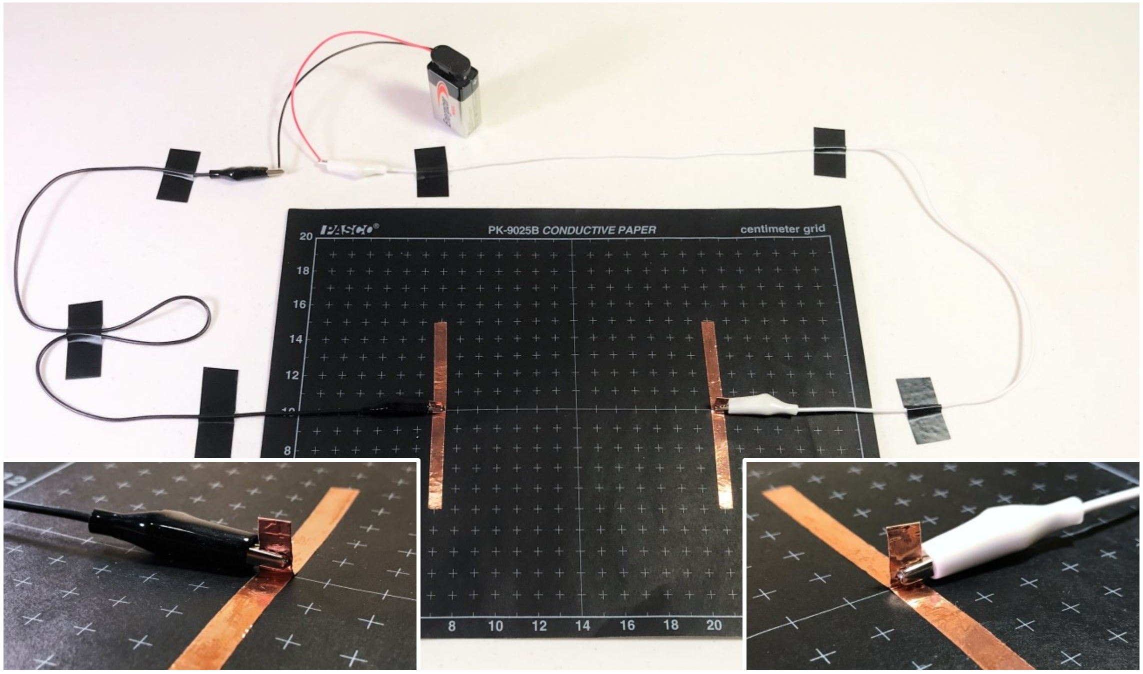


Fig. 7: Alligator clip wires are used to connect the battery to the strips of conductive tape. The alligator clips need to lie flat on their sides to minimize stress on the tabs. Electrical tape is useful for keeping the wires neat and in place.

9. Turn the multimeter dial to measure voltage (20 V range). Put the black multimeter probe in the common port (COM) and the red probe in the voltage port (V). Note: The ports on your multimeter may differ from those shown here.
10. Use an alligator clip wire to attach the black (common) multimeter probe to the negative pole of the battery (electrically, this is the same as connecting it to the negative conductive tape strip). The easiest way to do this is to connect the alligator clip to the clip already on the negative battery pole (see Fig. 8). The red multimeter probe will be used for checking voltages at various locations on the conductive paper.
11. Tape down the paper and all the wires to prevent them from moving during the experiment (see Fig. 8). If the wires shift, it can change the voltages and electric field.
12. Check that everything is set up correctly by first touching the red multimeter probe end to the conductive tape connected to the cathode (negative conductor) – the voltmeter should read 0V. Touch the probe to the tape connected to the anode (positive conductor) – the voltmeter should read approximately 9V. Firmly (but not enough to puncture the paper), press the probe tip against the paper at the halfway point between the two conductive strips. You should get roughly half of the 9V measurement. If you are not getting these voltages, check all the connections. See Fig. 9.

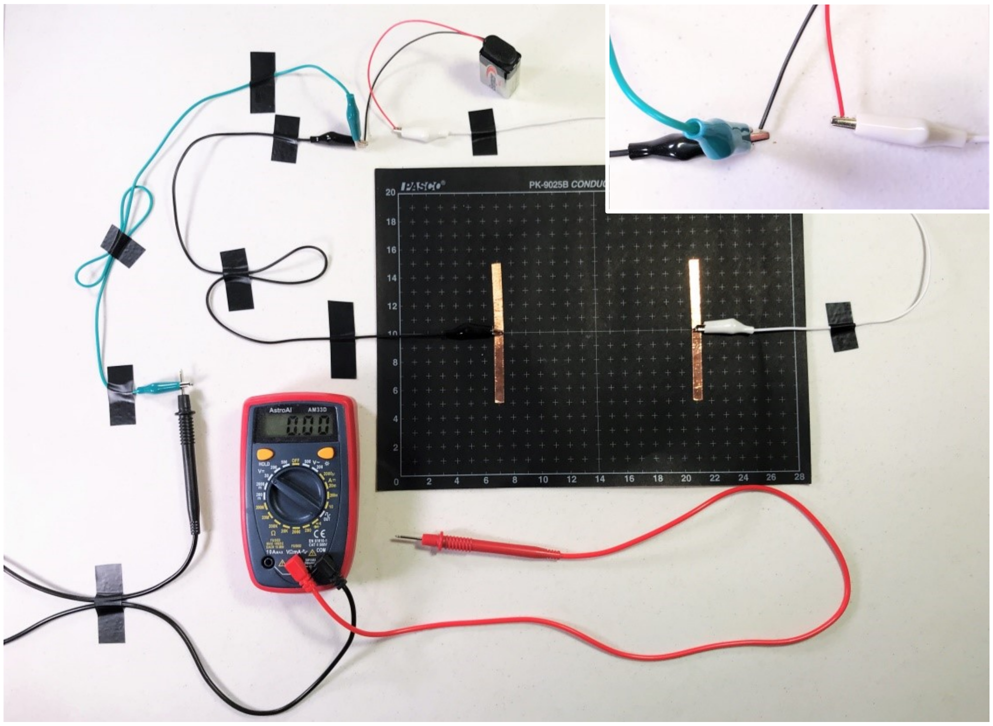


Fig. 8: Use an alligator clip wire to connect the black (common) multimeter probe to the negative battery terminal. In this example, a green wire was used for this purpose.

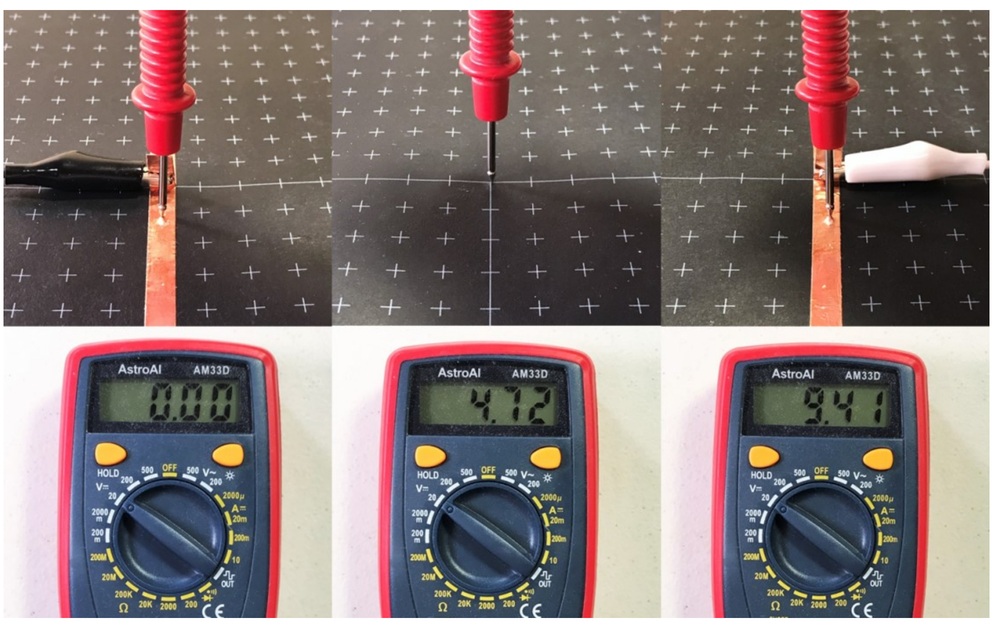


Fig. 9: Check the voltage on the negative strip, halfway between the two strips, and on the positive strip. You should see voltages of 0V, about 4.5V, and about 9V respectively. If the positive strip voltage is greater than 9V, then the halfway voltage should be about half of this value.

Draw Equipotential Lines

1. Search with your red probe on the conductive paper near the negative conductor (0V) and find a location where the voltage is +1.0 V. The probe reads most accurately when pressed straight down onto the paper rather than at an angle. Mark that location with the yellow china marker (see Fig. 10).

   Tip: Twisting the china marker is an easy way to leave a mark on the paper.

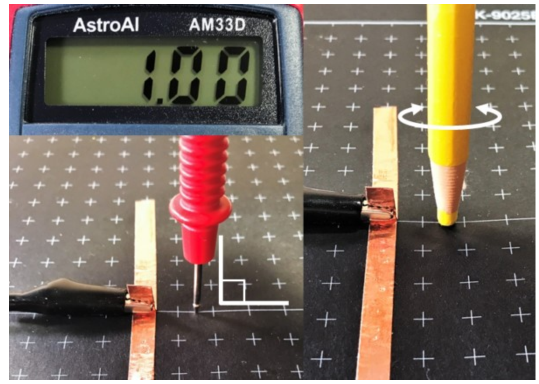
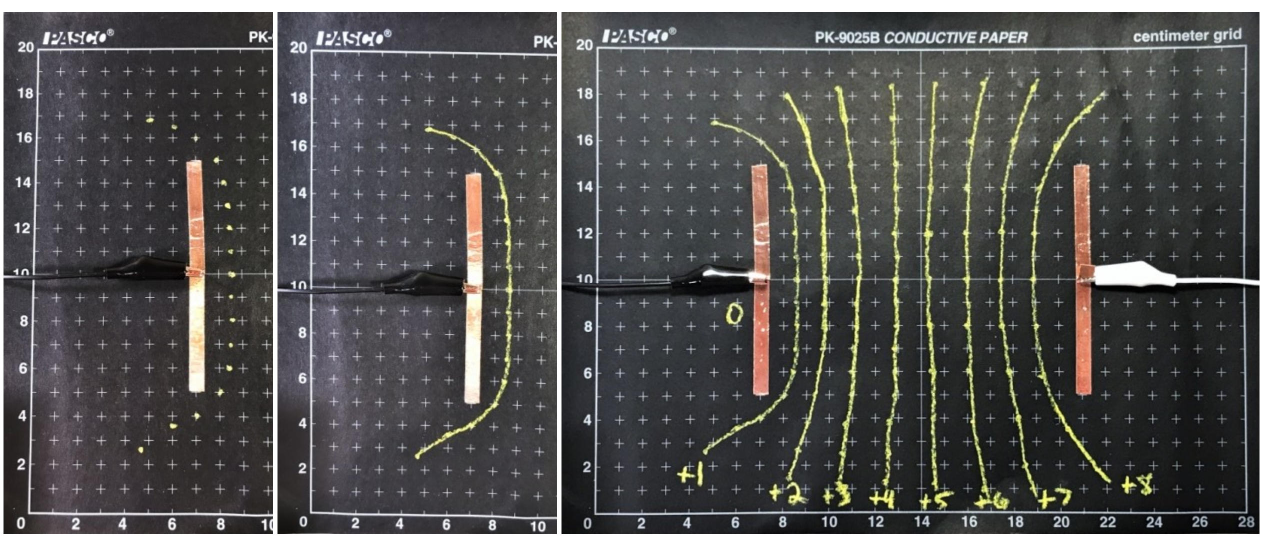


Fig. 10: Check the voltage near the negative strip to find a point where the voltage is +1.0 V. Mark that location with the yellow china marker.

   Warning: Once you start marking points on the paper, be careful to NOT adjust or bump the alligator clips on the conductive tape tabs. Slight adjustments could change the voltages and the electric field, making your previous marks inaccurate.

2. Search nearby for another location with +1.0 V and mark it as before.
3. Continue searching for points with +1.0 V until you have a line of points each with a potential of +1.0 V. It will curve out at the ends of the strip. See Fig. 11a.
4. Draw a line between the +1.0 V points as shown in Fig. 11b.
5. Repeat the previous steps for +2.0 V, +3.0 V, … +8.0 V and label the voltage of each. See Fig. 11c.



(a) (b) (c)

Fig. 11: (a) Find and mark a series of points with a voltage of +1.0 V. (b) Draw a line between the points to form the +1.0 V equipotential line. (c) Continue finding and marking points to plot the equipotential lines for +2.0 V, +3.0 V, … +8.0 V. Label each equipotential line with the voltage.

Draw Electric Field Lines

1. Use the red china marker to draw electric field lines between the two conductive strips. Follow the rule that electric field lines are perpendicular to each conductive strip and perpendicular to each equipotential line they cross. See Fig. 12.
2. Add arrows to the electric field lines to indicate their direction from high voltage toward low voltage. Electric field lines begin on the conductor with high potential (9V) and end on the conductor with low potential (0V).

   Notice both the uniformity of the electric field between the two parallel lines and the edge effects where the electric field “bulges” out at the ends of the lines.

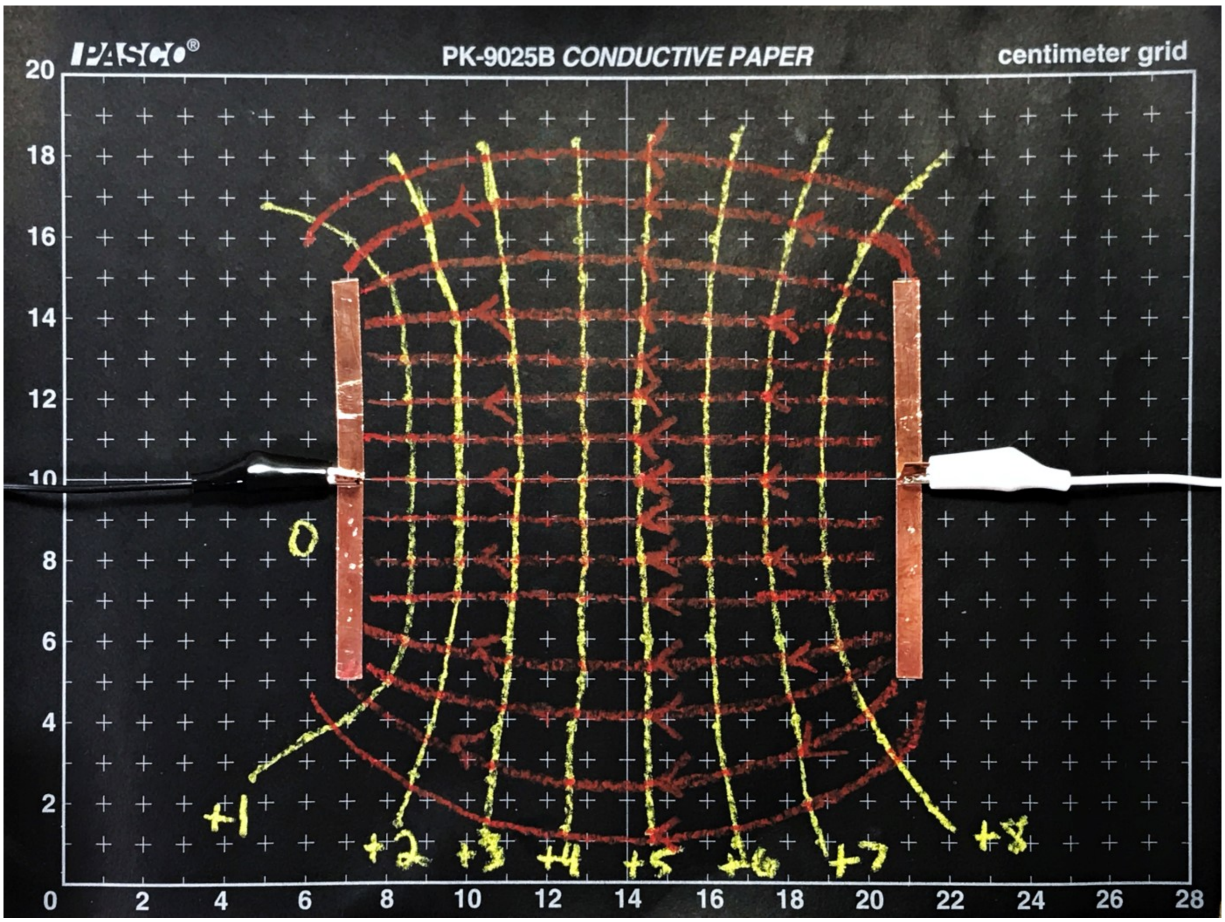


Fig. 12: Draw electric field lines from the conductor with high potential (9V) across to the conductor with low potential (0V). Add arrows to indicate the direction of the field lines.

IMPORTANT: When you finish the experiment, turn off the multimeter to save the battery.
The simpler inexpensive multimeters often do not shut off automatically.
Also, be sure to disconnect the battery from the conductive tape.

Analysis (Part 1):

Estimate Electric Field Strength

Estimate the nearly constant electric field strength between the equipotential lines by measuring the steepness of the voltage gradient.

1. Use a ruler to measure the distance between the equipotential lines in the center between the two conductors. You can measure between two adjacent lines (ex. measure distance between +4.0 V and +5.0 V) or if the line spacing in the center is fairly even, you could measure across several lines.
2. Use the measured distance along with the voltage difference to calculate the electric field strength according to Eq. (4) and Fig. 3.

Procedure (Part 2):

Point Conductors – Electric Dipole

An electric dipole consists of a positive and negative pair of point charges of equal magnitude separated by some distance.

Setup

1. Cut two lengths of conductive tape, each about 2-3 cm long. Fold each strip in half and trim the ends into semi-circles (see Fig. 13).
2. Fold the rounded ends of each strip so that the two semi-circles make a circle shape and the rest of the strip makes a tab for the alligator clip (see Fig. 13d).

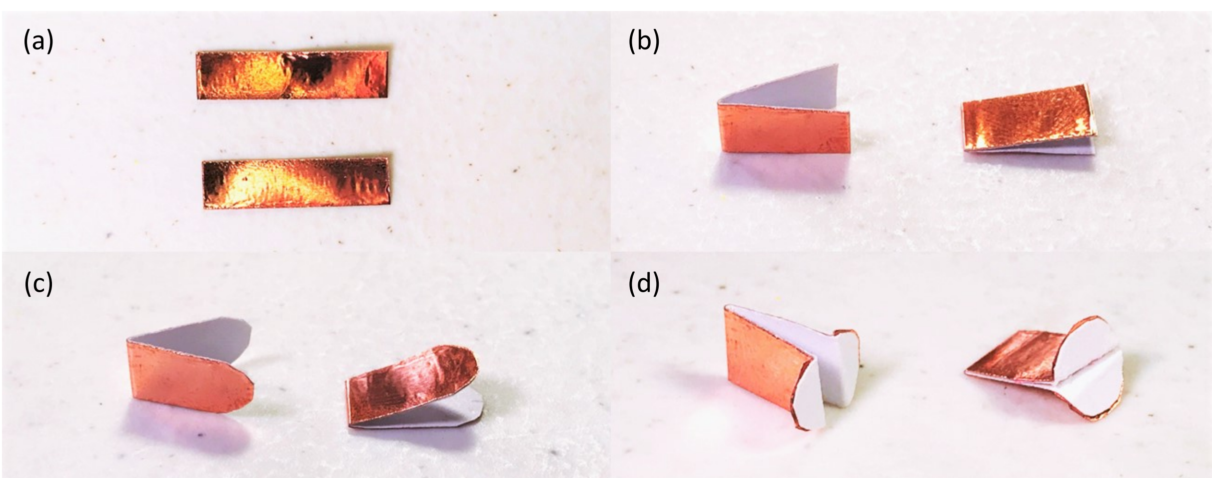


Fig. 13: (a) Cut two pieces of conductive tape each 2-3 cm long. (b) Fold each strip of tape in half. (c) Trim the ends of each strip into a semi-circle. If you trim the ends while folded, you can do both ends at once. (d) Fold the ends back to make a circle with a tab.

3. Carefully place each tab on a sheet of conductive paper at the points (7,10) and (21,10). See Fig. 14. Take extra care to place it correctly the first time. If you try to remove the tape, it will probably tear the paper.

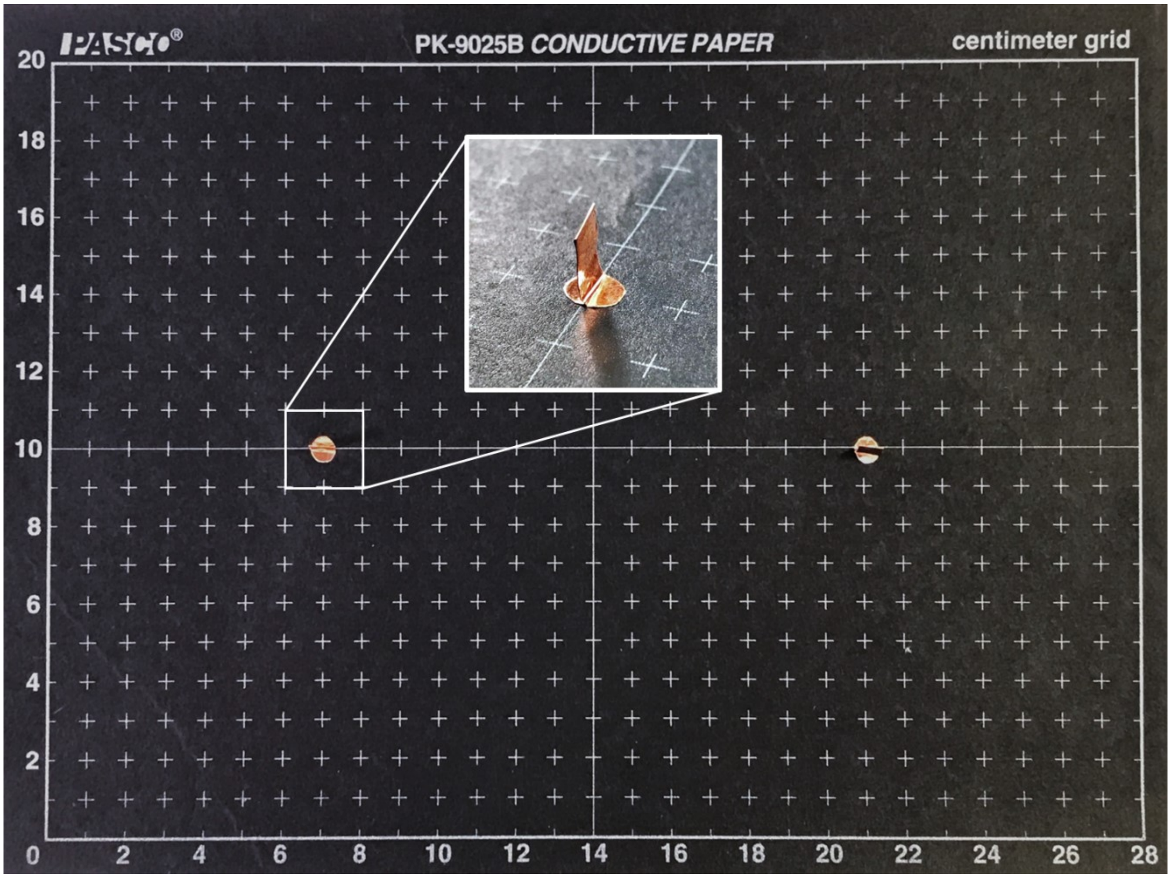


Fig. 14: Carefully place the conductive tape tabs on the conductive paper at the points (7,10) and (21,10). Be careful to place them correctly the first time because if you try to remove them, the paper will probably tear.

4. Snap the battery connector onto the battery.
5. Use an alligator clip wire (wire with alligator clip on each end) to connect the positive pole of the battery (anode – red battery connector wire) to one of the conductive tape tabs. You can choose which side you want to connect it to.
6. Use a second alligator clip wire to connect the negative pole of the battery (cathode – black battery connector wire) to the other conductive tape tab.
7. Arrange the alligator clips so that they lie flat on their insulating rubber and do not stress the conductive tape tabs. Electrical tape may be useful to secure the wires and hold everything down to the table. See Fig. 15.

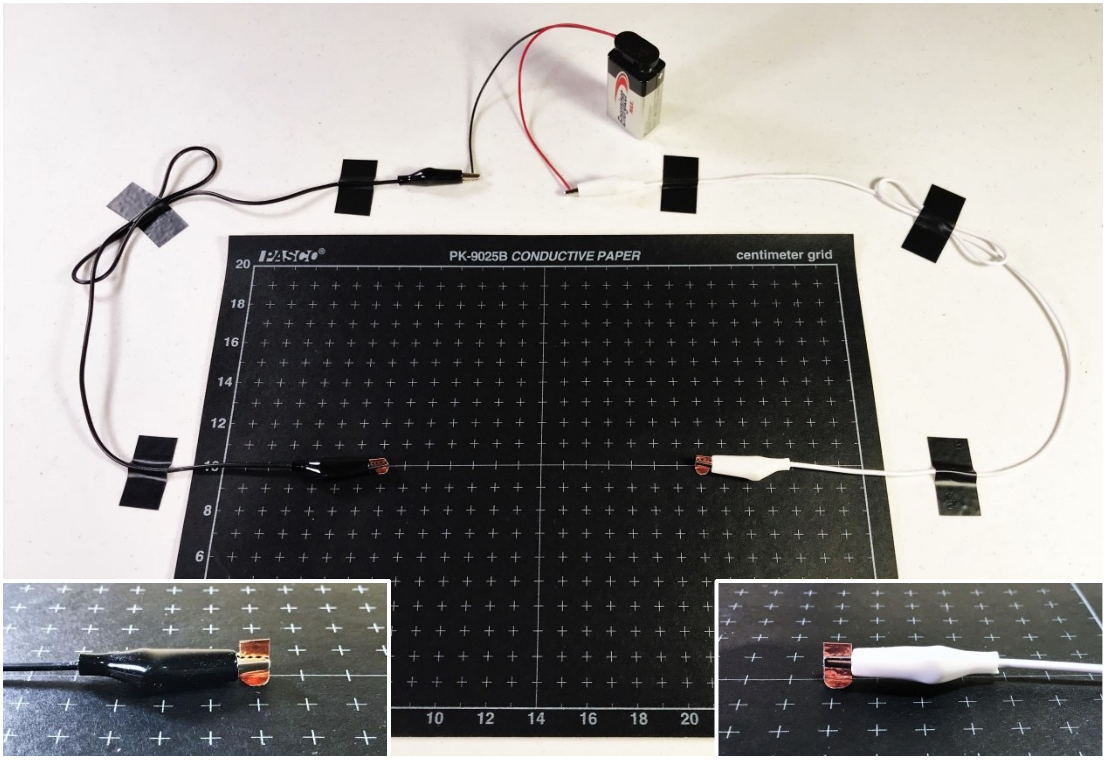


Fig. 15: Alligator clip wires are used to connect the battery to the conductive tape tabs. The alligator clips need to lie flat on their sides to minimize stress on the tabs. Electrical tape is useful for keeping the wires neat and in place.

8. Turn the multimeter dial to measure voltage (20 V range). Put the black multimeter probe in the common port (COM) and the red probe in the voltage port (V).
   Note: The ports on your multimeter may differ from those shown here.
9. Use an alligator clip wire to attach the black (common) multimeter probe to the negative pole of the battery (electrically, this is the same as connecting it to the negative conductive tape tab). The easiest way to do this is to connect the alligator clip to the clip already on the negative battery pole (see Fig. 16).
   The red multimeter probe will be used for checking voltages at various locations on the conductive paper.
10. Tape down the paper and all the wires to prevent them from moving during the experiment (see Fig. 16). If the wires shift, it can change the voltages and electric field.
11. Check that everything is set up correctly by first touching the red multimeter probe end to the conductive tape connected to the cathode (negative conductor) – the voltmeter should read 0V. Touch the probe to the tape connected to the anode (positive conductor) – the voltmeter should read approximately 9V. Firmly (but not enough to puncture the paper), press the probe tip against the paper at the halfway point between the two conductors. You should get roughly half of the 9V measurement. If you are not getting these voltages, check all the connections. See Fig. 17.

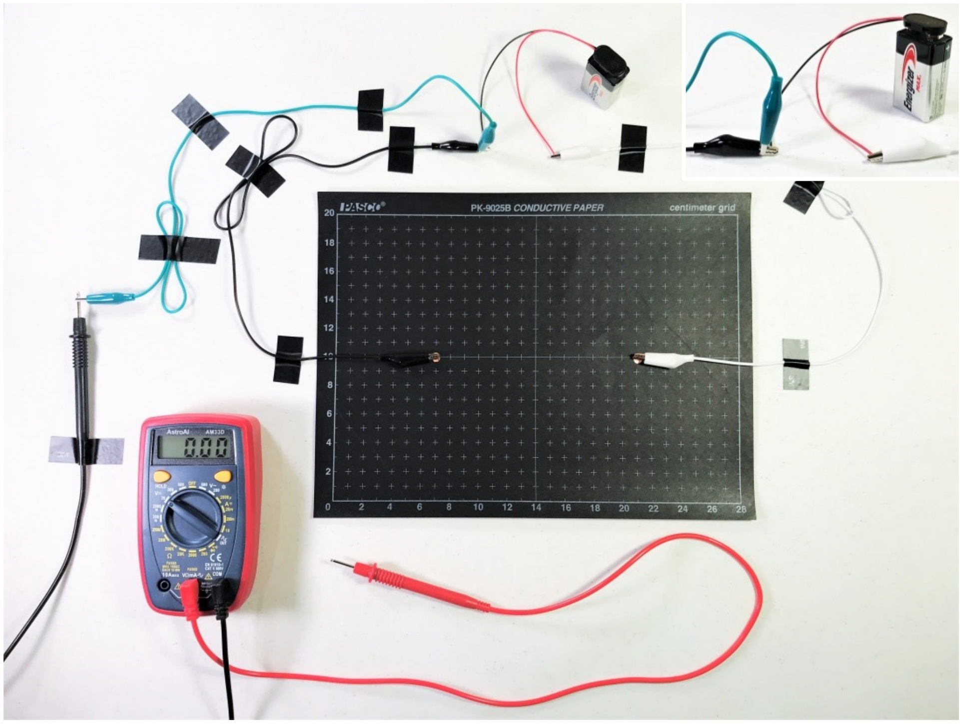


Fig. 16: Use an alligator clip wire to connect the black (common) multimeter probe to the negative battery terminal. In this example, a green wire was used for this purpose.

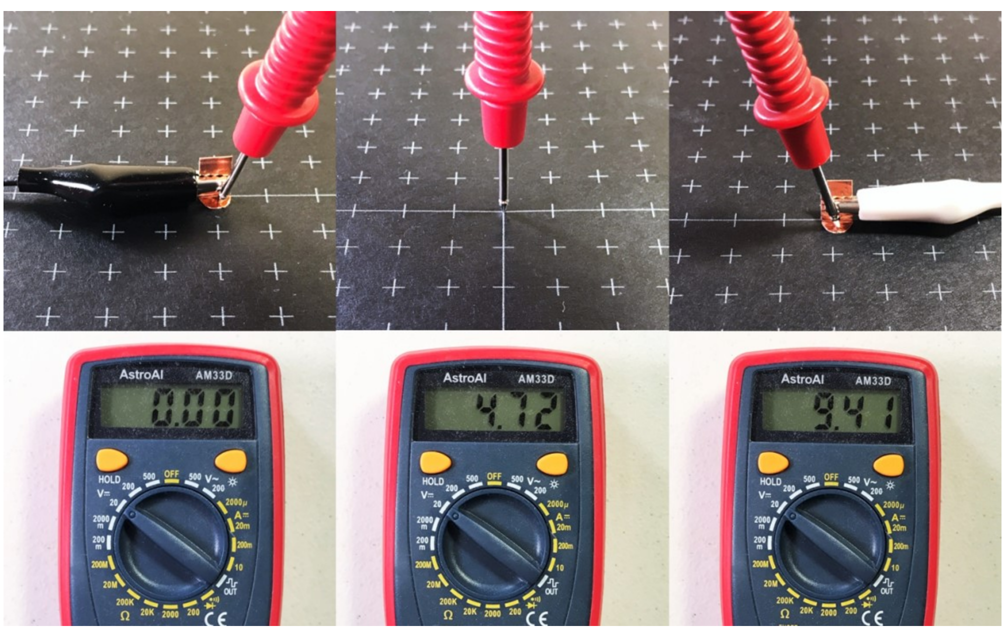


Fig. 17: Check the voltage on the negative conductor, halfway between the two conductors, and on the positive conductor. You should see voltages of 0V, about 4.5V, and about 9V respectively. If the positive conductor voltage is greater than 9V, then the halfway voltage should be about half of this value.

Draw Equipotential Lines

1. Search with your red probe on the conductive paper near the negative conductor (0V) and find a location where the voltage is +2.0 V (+1.0 V will likely be too close to the tape to find). The probe reads most accurately when pressed straight down onto the paper rather than at an angle. Mark that location with the yellow china marker (see Fig. 18).

   Tip: Twisting the china marker is an easy way to leave a mark on the paper.

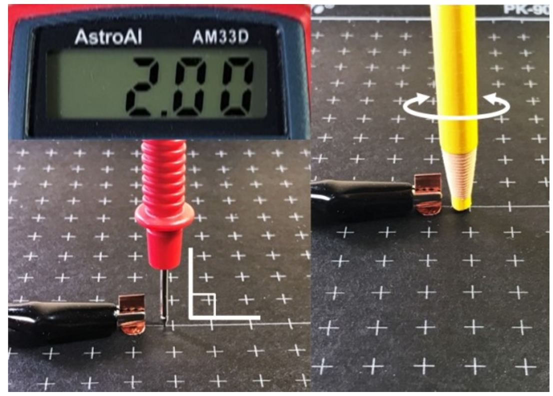
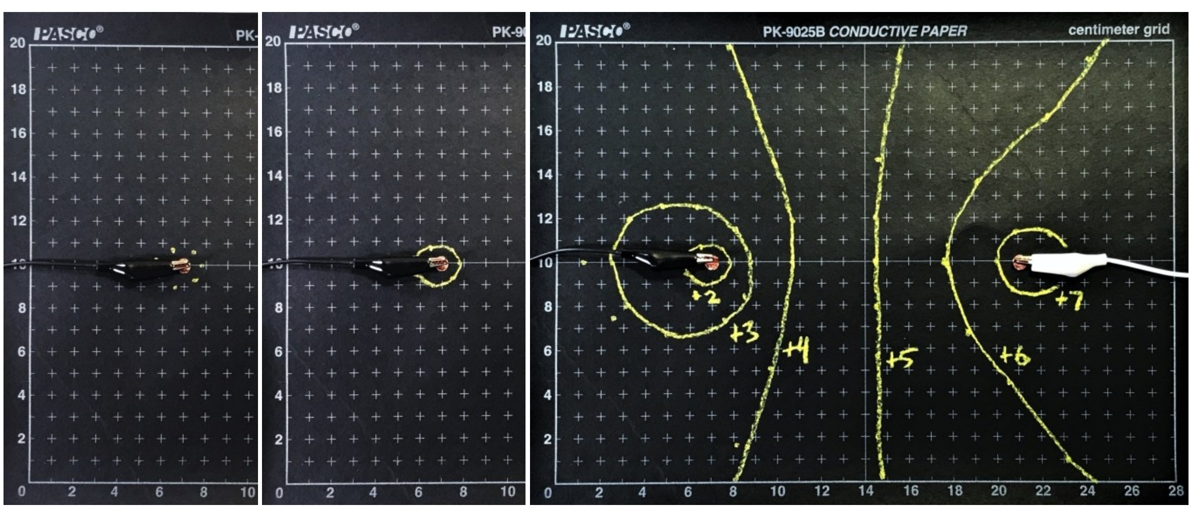


Fig. 18: Check the voltage near the negative conductor to find a point where the voltage is +2.0 V. Mark that location with the yellow china marker.

Warning: Once you start marking points on the paper, be careful to NOT adjust or bump the alligator clips on the conductive tape tabs. Slight adjustments could change the voltages and the electric field, making your previous marks inaccurate.

2. Search nearby for another location with +2.0 V and mark it as before.
3. Continue searching for points with +2.0 V until you have a circular line of points each with a potential of +2.0 V (see Fig. 19a).
4. Draw a curved line through the +2.0 V points as shown in Fig. 19b.
5. Repeat the previous steps for +3.0 V, +4.0 V, … +7.0 V and label the voltage of each. See Fig. 19c.



(a) (b) (c)

Fig. 19: (a) Find and mark a series of points with a voltage of +2.0 V. (b) Draw a line between the points to form the +2.0 V equipotential line. (c) Continue finding and marking points to plot the equipotential lines for +3.0 V, +4.0 V, … +7.0 V. Label each equipotential line with the voltage.

Draw Electric Field Lines

1. Use the red china marker to draw electric field lines between the two conductors. Follow the rule that electric field lines are perpendicular to the edge of each conductor and perpendicular to each equipotential line they cross. See Fig. 20.
2. Add arrows to the electric field lines to indicate their direction from high voltage toward low voltage. Electric field lines begin on the conductor with high potential (9V) and end on the conductor with low potential (0V).

   Notice that centrally between the positive and negative conductors, the electric field lines are nearly straight and the equipotential lines fall at a nearly steady rate.

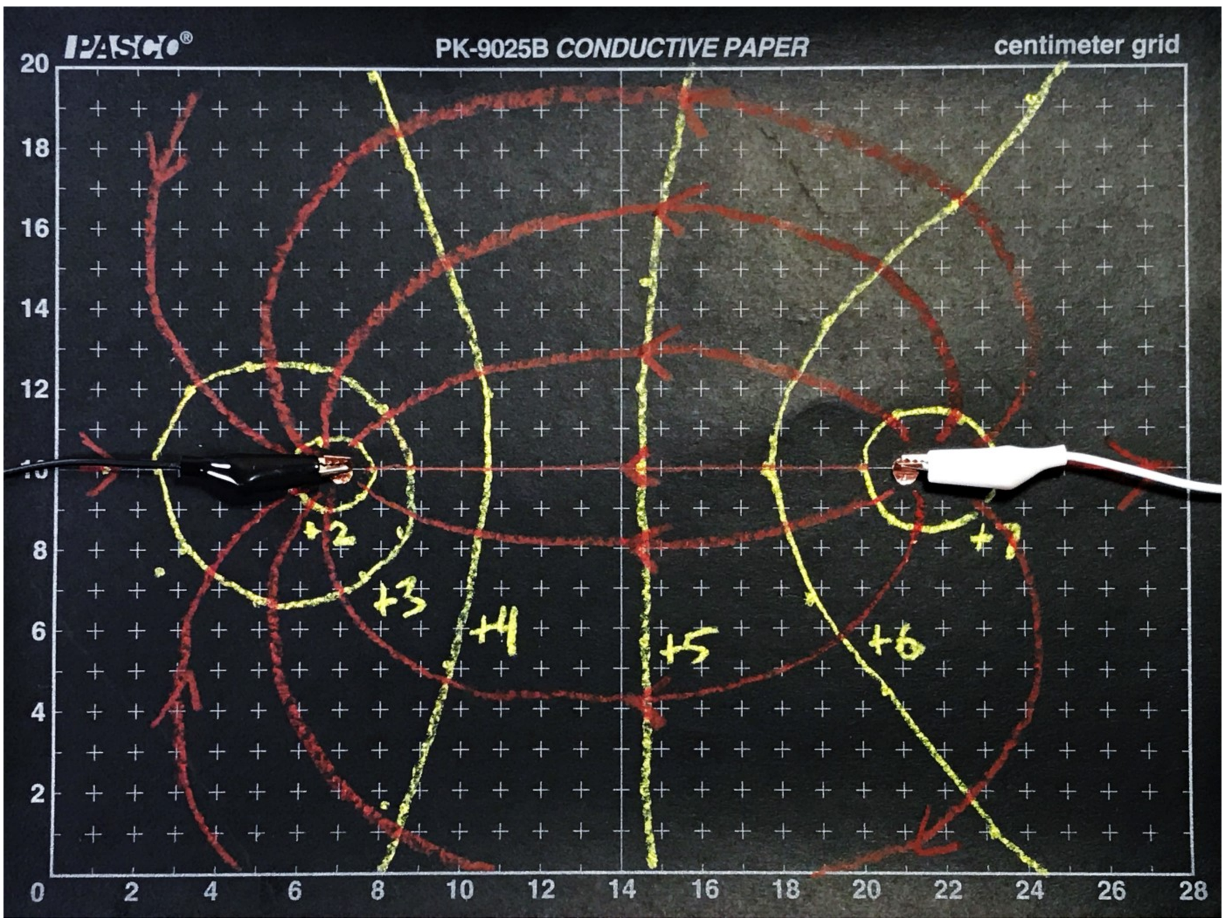


Fig. 20: Draw electric field lines from the conductor with high potential (9V) across to the conductor with low potential (0V). Add arrows to indicate the direction of the field lines.

IMPORTANT: When you finish the experiment, turn off the multimeter to save the battery.
The simpler inexpensive multimeters often do not shut off automatically.
Also, be sure to disconnect the battery from the conductive tape.

Analysis (Part 2):

Estimate Electric Field Strength

Estimate the electric field strength between the two conductors by measuring the steepness of the voltage gradient.

1. Use a ruler to measure the distance between the equipotential lines in the center between the two conductors. You can measure between two adjacent lines (ex. measure distance between +4.0 V and +5.0 V) or if the line spacing in the center is fairly even, you could measure across several lines (ex. measure distance between +4.0V and +6.0V).
2. Use the measured distance along with the voltage difference to calculate the electric field strength according to Eq. (4) and Fig. 3.