Equipotential Lines and Electric Fields

Plotting the Electric Field

MATERIALS AND RESOURCES

EACH GROUP

5 alligator clip leads

2 batteries, 9 V

2 binder clips, large

computer

LabQuest®

multimeter,
 seven-function

picture frame,
 plastic box-style,
 8.5 in. × 11 in.

sensor, voltage probe

ruler, clear metric

tape, masking

2 pieces wires,
 copper, #16 gauge,
 approx. 20 cm

TEACHER

wire cutter

wire, copper,
 #16 gauge

ABOUT THIS LESSON

The electrical field produces a force that acts between two charges in the same way that the gravitational field force acts between two masses. In this activity students will measure potentials that exist between charged regions, then plot electric fields which are implied by these differences in potential.

OBJECTIVES

Students will:

- Investigate the space between a pair of electrodes that are connected to a source of direct current
- Plot and examine the plot in terms of the implied electric field

LEVEL

Physics

COMMON CORE STATE STANDARDS

(MATH) A-CED.2

Create equations in two or more variables to represent relationships between quantities; graph equations on coordinate axes with labels and scales.

(MATH) S-ID.6B

Represent data on two quantitative variables on a scatter plot, and describe how the variables are related. Informally assess the fit of a function by plotting and analyzing residuals.

(LITERACY) RST.9-10.3

Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

(LITERACY) RST.9-10.7

Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

(LITERACY) RST.9-10.10

By the end of grade 10, read and comprehend science/technical texts in the grades 9-10 text complexity band independently and proficiently.

(LITERACY) W.1

Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.

(LITERACY) W.4

Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

(LITERACY) W.3

Write narratives to develop real or imagined experiences or events using effective technique, well-chosen details, and well-structured event sequences.

(MATH) A-CED.4

Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations. For example, rearrange Ohm's law $V = IR$ to highlight resistance R.

(MATH) F-LE.2

Construct linear and exponential functions, including arithmetic and geometric sequences, given a graph, a description of a relationship, or two input-output pairs (include reading these from a table).

(MATH) F-LE.5

Interpret expressions for functions in terms of the situation they model. Interpret the parameters in a linear or exponential function in terms of a context.

(MATH) N-Q.1

Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

(MATH) S-ID.6A

Represent data on two quantitative variables on a scatter plot, and describe how the variables are related. Fit a function to the data; use functions fitted to data to solve problems in the context of the data. Use given functions or choose a function suggested by the context. Emphasize linear, quadratic, and exponential models.

TEACHER PAGES

ASSESSMENTS

The following types of formative assessments are embedded in this lesson:

- Assessment of prior knowledge
- Guided questions
- Assessments of Process Skills

The following additional assessments are located on our website:

- Physics Assessment: Electrostatics
- 2010 Physics Posttest, Free Response Question 2; 2008 Physics Posttest, Free Response Question 3; Physics Posttest, Free Response Question 2.

ACKNOWLEDGEMENTS

NEXT GENERATION SCIENCE STANDARDS
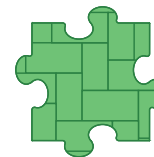
DEVELOPING AND USING MODELS

ANALYZING AND INTERPRETING DATA

OBTAINING/EVALUATING COMMUNICATING

CAUSE AND EFFECT

ENERGY AND MATTER

PATTERNS

PS2: FORCES AND INTERACTION

PS3: ENERGY

PS4: WAVES

TEACHER PAGES

TEACHING SUGGESTIONS

The concept of electric fields was introduced by Michael Faraday. The *electric field* is the region where the force on one charge is caused by the presence of another charge. The electric field is a vector quantity and by convention, electric fields emanate from positive charges and terminate on negative charges (Figure A).
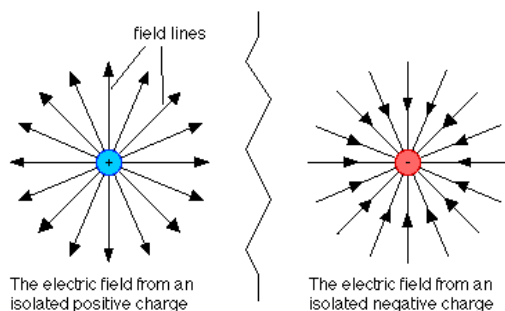

field lines

The electric field from an isolated positive charge

The electric field from an isolated negative charge

Figure A. Electric field

Plastic picture frames are available from retail stores in either 8 in. × 10 in. or 8.5 in. × 11 in. sizes. These frames consist of a plastic box with a cardboard back for holding pictures. The box makes a good flat container for holding a thin film of water. The picture frames should be kept as level as possible so that the electric field does not appear distorted. The water level should be kept shallow, just covering the bottom of the frame completely.

When the circuit is connected, chemical reactions will also start that will corrode the tips of the copper wire and will change the resistance, and thus will also distort the shape of the field if left too long. After each period, the copper wires should be cleaned with sandpaper or scraped clean. The plastic frames should be cleaned after each class period to avoid a build-up of copper compounds.

The most likely chemical reactions are

- $Cu \rightarrow Cu^{+2} + 2e^-$
- $H_2O + 2e^- \rightarrow H_2 + O^{-2}$
- $CO_2 + O^{-2} \rightarrow CO_3^{-2}$
- $Cu^{+2} + CO_3^{-2} \rightarrow CuCO_3 \cdot H_2O$ (*s*), a light blue precipitate

There is also a science literacy piece that accompanies this lesson which requires students to interpret the soundness of articles written about the dangers of electromagnetic fields. ✖
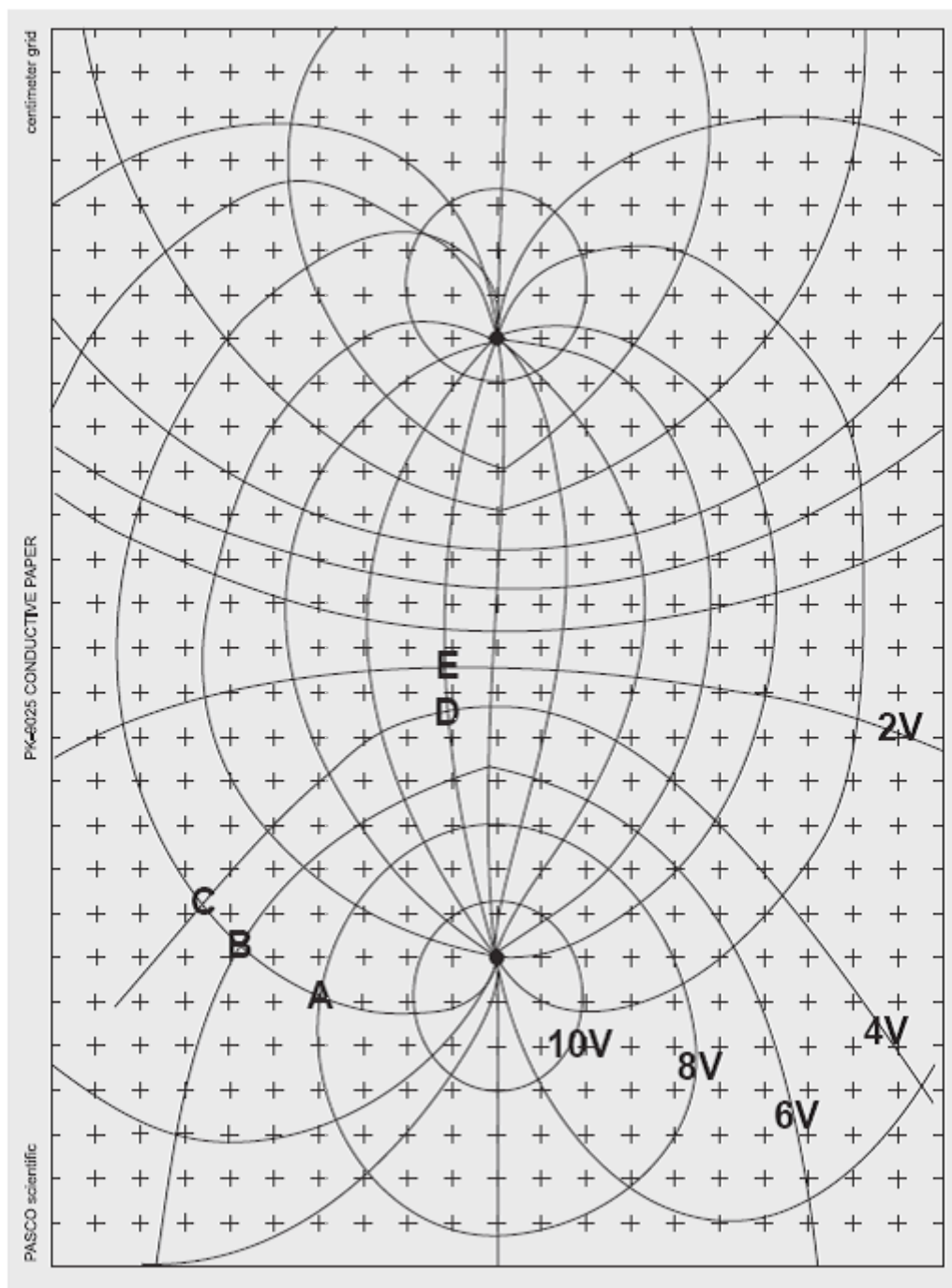
TEACHER PAGES

ANSWER KEY

DATA AND OBSERVATIONS

Figure A. Equipotential lines, point probe

T E A C H E R   P A G E S
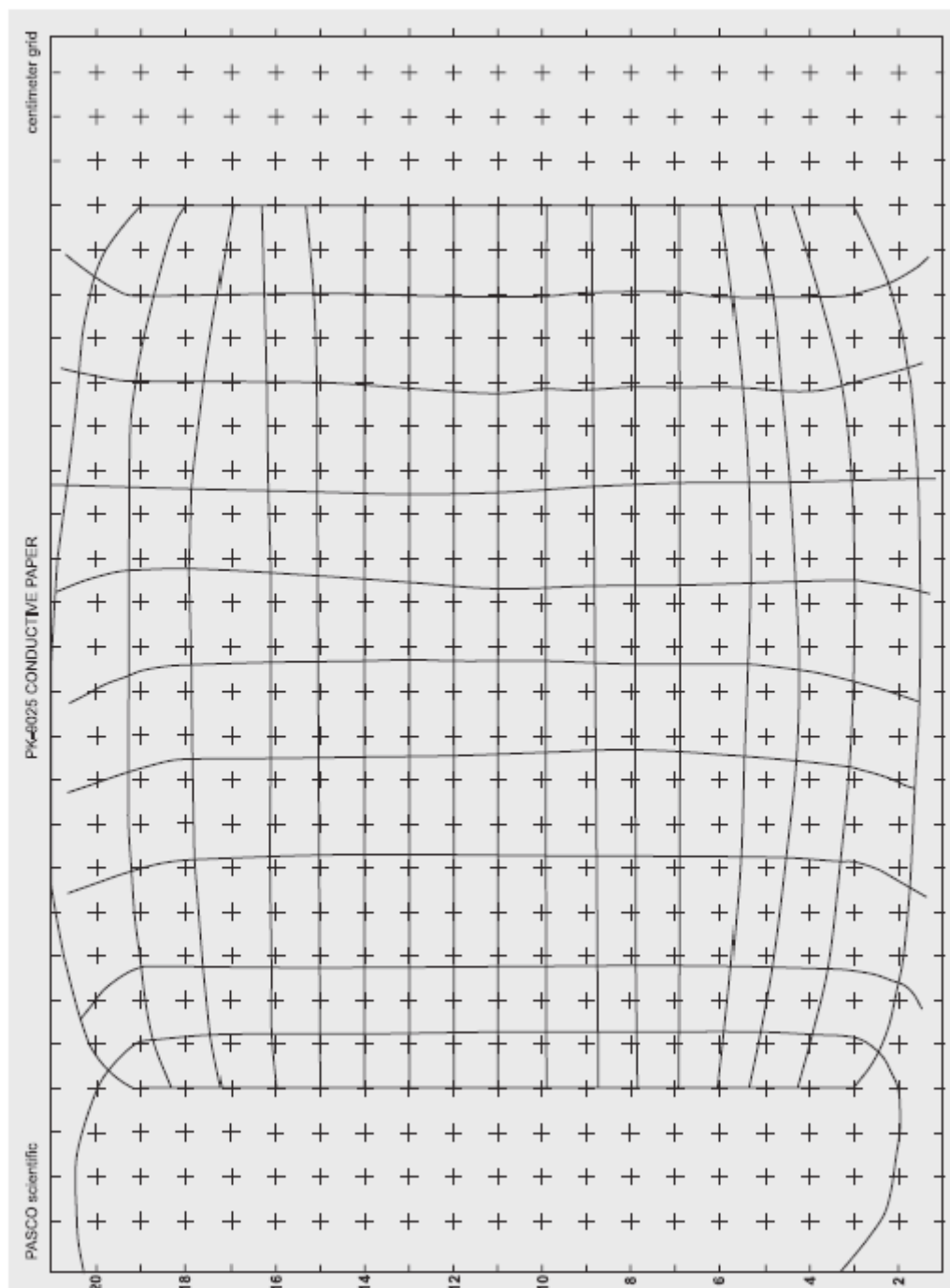
ANSWER KEY (CONTINUED)

Figure B. Equipotential lines, parallel line probe

ANSWER KEY (CONTINUED)

ANALYSIS

1. The electric field is constant on the straight line between the two charges. The electric field is not constant along the curved electric field lines.
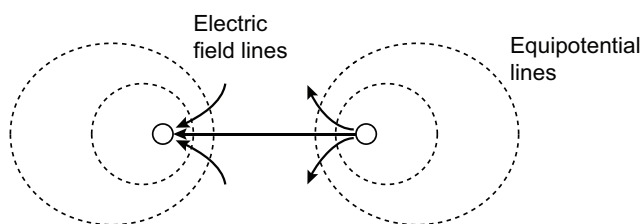
Electric field lines

Equipotential lines

Figure C. Equipotential and electric field lines, point source

2. For example, choose two equipotential lines, one at 10 V and 0.04 m from the positive terminal and one at 2 V and 0.06 m from the positive terminal. The electric field between them can be approximated as

$$E = \frac{V}{d} = \frac{10\,\text{V} - 2\,\text{V}}{0.06\,\text{m} - 0.04\,\text{m}} = 400 \text{ V/m} = 400 \text{ N/C}$$

Notice that the units V/m are equivalent to force per unit of charge, newtons per coulomb (N/C).

Table 1. Calculating Electric Field Strength				
Line	Contact Points	Voltage (V)	Distance (m)	Electric Field (V/m)
1	A to C	8 − 4 = 4	0.039	100
2	B to D	6 − 2 = 4	0.046	90
3	C to D	4 − 2 = 2	0.021	100
4	A to G	8 − (−4) = 12	0.107	110
5	C to I	4 − (−8) = 12	0.127	90

3. The electric field between the point charges varies depending on the distance from each charged point, becoming weaker with increasing distance. The electric field between the parallel lines is relatively constant.
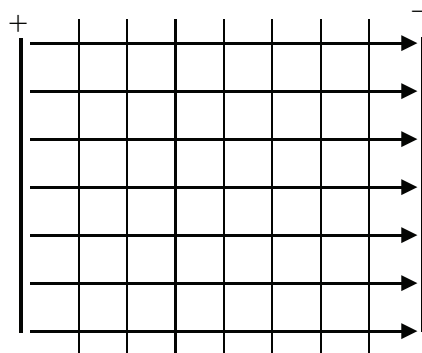
Figure D. Equipotential and electric field lines, parallel lines

TEACHER PAGES

ANSWER KEY (CONTINUED)

CONCLUSION QUESTIONS

1. An *electric field* is a region in space where one charge experiences a force from another charge. *Electric potential* is the amount of energy stored in an electric charge due to its position in an electric field. The strength of an electric field is directly related to the magnitude of the electric charge producing the field.

2. Electric field lines begin on positive charges and radiate away from them toward negative charges, where they terminate.

3. *Equipotential lines* are lines connecting points of the same electric potential. All electric field lines cross all equipotential lines perpendicularly.

4. a. The work along an electric field line depends on the magnitude of the charge and the potential difference through which the charge is moved.

   b. No work is required to move a charge along an equipotential line because no force is required, and there is no change in potential.

5. a. Closely spaced electric field lines indicate a strong electric field. The closer the lines, the stronger the electric field.

   b. Equally spaced electric field lines indicate the electric field is uniform.

TEACHER PAGES

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Plotting the Electric Field

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multimeter, seven-function

picture frame, plastic box-style, 8.5 in. × 11 in.

sensor, voltage probe

ruler, clear metric

tape, masking

*2 pieces wires, copper, #16 gauge, approx. 20 cm*

PURPOSE

In this experiment, the concept of *electric field* will be developed by investigating the space between a pair of electrodes connected to a source of direct current. You will plot equipotential lines and sketch in lines representing the electric field between the electrodes.

PROCEDURE

RUN #1

1. Tape the grid diagram with the squares and dots on the outside face of the plastic container, aligning the edges so that it can be seen through the picture frame.

2. Prepare two pieces of copper wire each approximately 50 cm in length. (If the wire is insulated, remove about 1 cm of insulation from each end.)

    Place the wires over the edge of the plastic frame and clip them securely, one to each short side, using a binder clip. Adjust the wires so that the point is down and directly over one of the dots on the paper diagram.

3. Snap the two 9-V batteries together so the positive terminal of one connects to the negative terminal of the other. This essentially makes a battery with a potential of 18 V.

4. Using an alligator clip, connect the negative terminal of the battery to one of the wires attached to the picture frame with the binder clip. Attach the other wire to the positive terminal of the battery with another alligator clip.

    Using a third alligator clip, connect the common or black lead from the voltmeter to the center where the two batteries are clipped together. For the compete setup, see Figure 1.

Figure 1. Experimental setup, point probes

Picture Frame with about 1/2 cm of Water
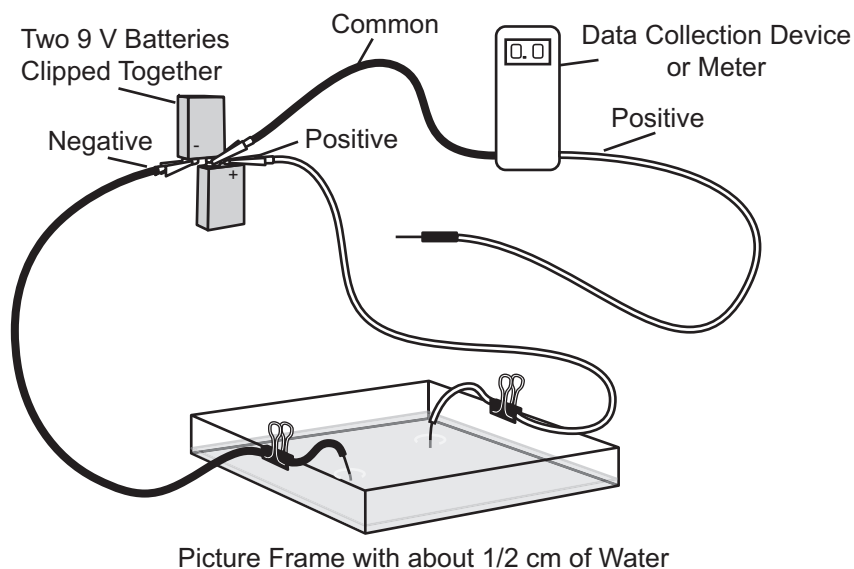
Check that the alligator clips are connected to the positive and negative terminals and are not also touching the casing of any of the batteries.

PROCEDURE (CONTINUED)

5. Add enough tap water to just evenly cover the bottom of the plastic container. Turn the voltmeter on, making sure it is set for DC volts and to the smallest range greater than 6 V. The positive or red lead of the meter is used to measure the potential in the water.

6. Data Collection

    a. *Manual* – Using a second grid, have your lab partner write down the measurements as you move the probe from dot to dot along the rows of dots. Try to keep the probe straight and make sure the water depth is the same all over the plastic container.

        Move as quickly as you can. Do not be concerned that the readings will not be steady. These are digital averaging meters. Allow the meter to adjust, and record the number that stays displayed for the longest period of time.

    b. *Alternate* – You may also use a data collection device with a voltage sensor to collect data. This data may be exported to your data analysis software or directly onto a computer with Microsoft Excel®. You may use this alternate procedure to speed up data collection and enhance the analysis.

        One partner should place the probe as you move from dot to dot along the rows. When the reading stabilizes somewhat, your lab partner should press the appropriate button to collect and record the data point on the device or software.

        Make sure that the stored data set is always moved to the end of the table. This may need to be done manually when the data is moved into your spreadsheet software.

        Each data set may be accompanied with an event number or other designation. You will need to remove all these extra columns, leaving only the voltage readings for the corresponding cells. Select each of these columns and delete them, leaving only the potentials in the spreadsheet.

PROCEDURE (CONTINUED)

7. After completing the measurements, enter or import the data into a Microsoft Excel® spreadsheet.

   When the data is entered, follow these steps to generate a graph:

   a. Use the cursor to highlight all the data.

   b. From the "Insert" menu, select "Chart."

   c. Pick the "Surface" plot from the standard types and "3-D Surface" as the subtype.

   d. Select "Finish" and examine the resulting graph.

   The graph may be rotated by grabbing a corner with the cursor and moving the corner to view the graph from different perspectives. In newer versions of Excel, you will need to use the dialog box to rotate the plot to view it from various angles to see the potential peaks and potential wells.

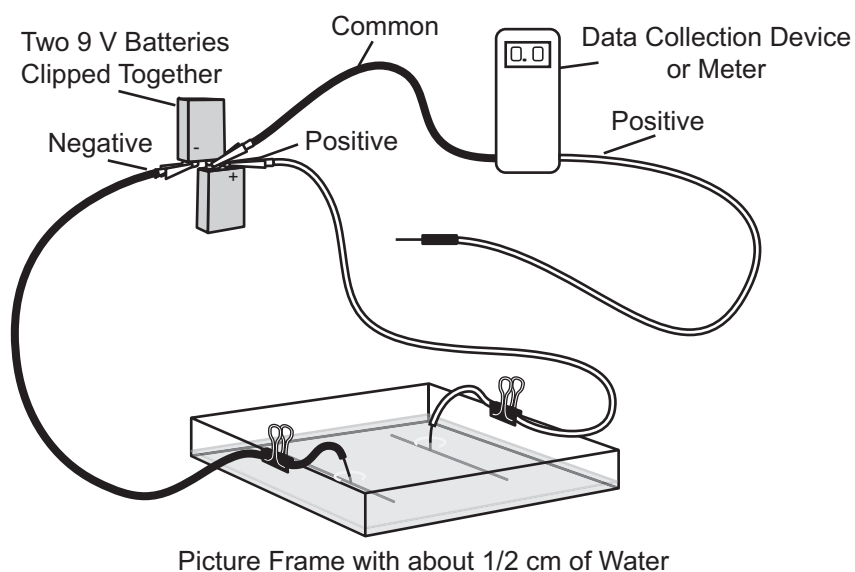8. To complete the analysis, view and print the graph viewed from directly above.

   This is not the best view to gain insight into the significance of both equipotential and electric field lines. However, printing the graph from this angle will be best for completing the Data and Observations section of the student pages.

   You may need to change the number of divisions along each axis, especially the potential axis, to produce a smoother plot showing more equipotential and field lines.

PROCEDURE (CONTINUED)

RUN #2

Repeat the entire procedure except instead of the ends of the wire touching the grid dots, add straight pieces of clean copper wire so they make parallel lines (Figure 2). Repeat the data collection and analysis.

Figure 2. Experimental setup, parallel line probes

Two 9 V Batteries Clipped Together

Common

Data Collection Device or Meter

Negative

Positive

Positive

Picture Frame with about 1/2 cm of Water

DATA AND OBSERVATIONS

After both sets of equipotential lines are drawn, draw a set of electric field lines starting from the positive 20 V and going to 0 V, crossing each equipotential line perpendicular to the line (Figure 3).

Figure 3. Equipotential and electric field lines
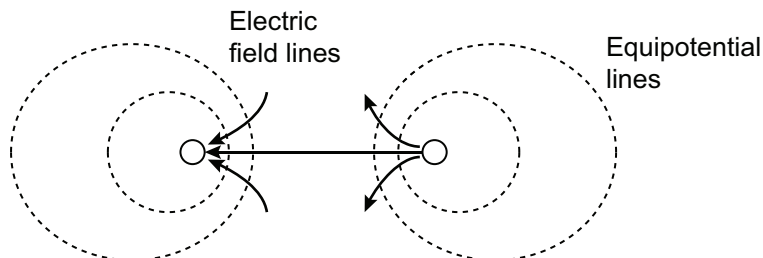
Begin by drawing the first line straight between the two pins. Draw five additional lines above and five lines below this straight line, keeping the newly drawn lines perpendicular to each equipotential line. Repeat this procedure for the other sheet.

These perpendicular lines that you have drawn on the paper represent the electric field between the two electrodes. The electric field lines are always directed from positive to negative (or from greater positive potential to lesser positive potential).

When the data is copied and exported into Excel extra columns ("Event", Figure 4) may have to be deleted, leaving only the voltage data in the spreadsheet.

Figure 4. Data as it appears in Logger Pro

	Run 1		Run 2		Run 3		Run 4		Run 5		Run 6		
	Event	Potential (V)	Event	Potential (V)	Event	Potential (V)	Event	Potential (V)	Event	Potential (V)	Event	Potential (V)	Event
1	1	1.082	1	0.840	1	0.593	1	-0.046	1	-0.527	1	-0.836	
2	2	1.131	2	0.950	2	0.683	2	0.028	2	-0.411	2	-0.761	
3	3	1.258	3	1.091	3	0.835	3	0.239	3	-0.235	3	-0.631	
4	4	1.471	4	1.338	4	1.101	4	0.541	4	0.016	4	-0.346	
5	5	1.702	5	1.625	5	1.461	5	1.016	5	0.508	5	-0.043	
6	6	1.921	6	1.876	6	1.907	6	1.743	6	1.162	6	0.337	
7	7	2.085	7	2.195	7	2.482	7	3.118	7	2.586	7	1.016	
8	8	2.151	8	2.254	8	2.164	8	2.943	8	2.297	8	0.861	
9	9	2.071	9	2.113	9	1.759	9	1.880	9	1.299	9	0.544	
10	10	1.975	10	1.900	10	1.455	10	1.236	10	0.750	10	0.119	
11	11	1.760	11	1.676	11	1.182	11	0.829	11	0.286	11	-0.244	
12	12	1.587	12	1.486	12	1.035	12	0.556	12	0.071	12	-0.478	
13	13	1.470	13	1.350	13	0.164	13	0.378	13	-0.089	13	-0.584	

DATA AND OBSERVATIONS (CONTINUED)

The following graphs represent sample data generated from Excel.

Figure 5. Three-dimensional plot of potential
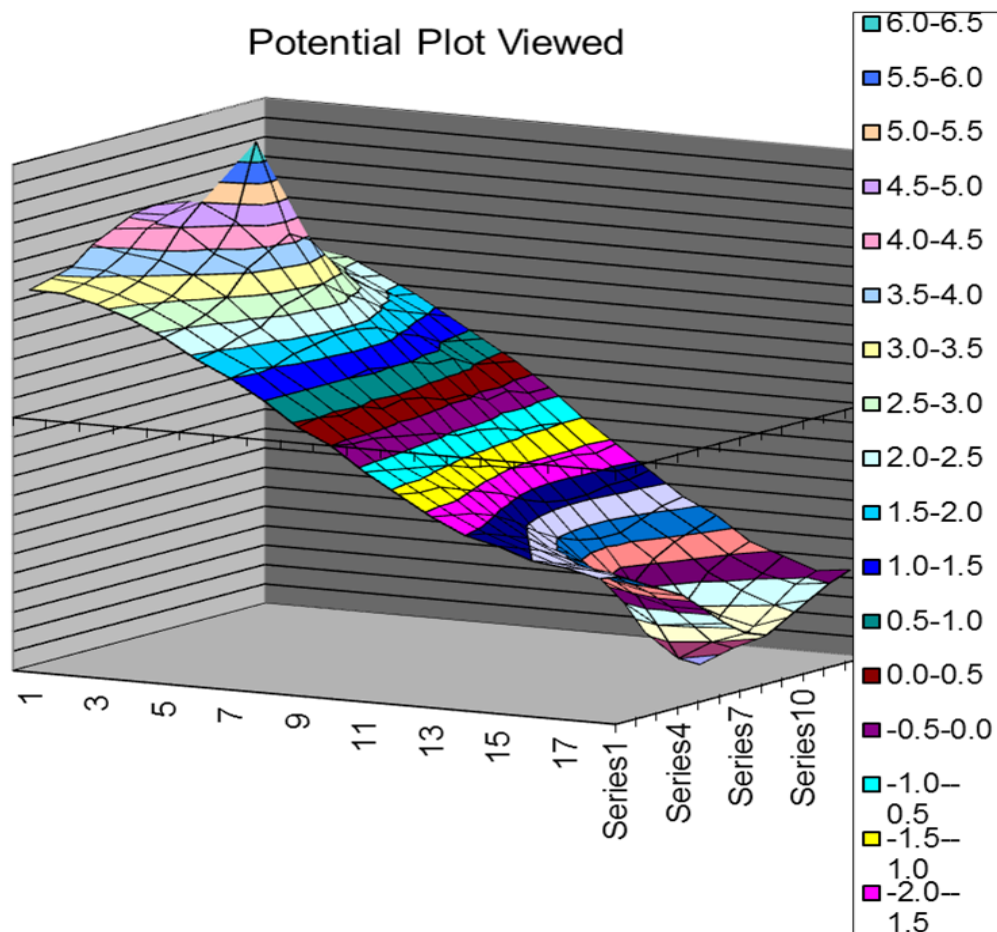
DATA AND OBSERVATIONS (CONTINUED)
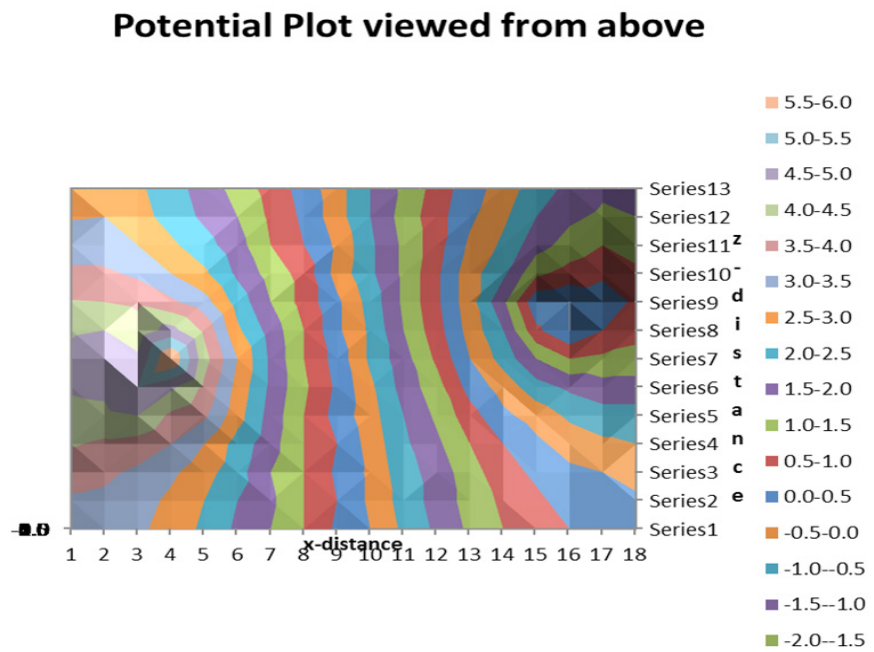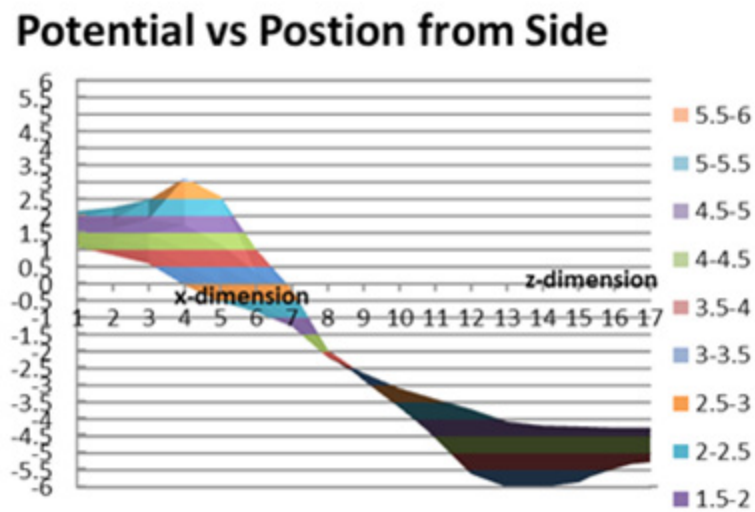
Figure 6. Plot of potential viewed from above

Potential Plot viewed from above

Figure 7. Plot of potential viewed from side

Potential vs Postion from Side

ANALYSIS

1. The strength of an electric field is measured in units of volts per meter. The field strength at a point is found by selecting a second point fairly close to the first and dividing the difference in voltage between the two points by the distance in meters between the electric field lines:

$$E = \frac{V}{d} \qquad \text{(Eq. 1)}$$

Make a sketch of the equipotential and electric field lines in the space provided. Where is the electric field constant?

2. Using the sheet with the parallel conducting lines, select two points along the same field line and measure the difference in potential between the points and the distance between them. Use Equation 1 to calculate the strength of the field.

Calculate the field strength for five pairs of points between the parallel lines from the second sheet of paper. Record your values in Table 1 and make a sketch of the equipotential and field lines in the space provided.

ANALYSIS (CONTINUED)

Table 1. Calculating Electric Field Strength				
Line	Contact Points	Voltage (V)	Distance (m)	Electric Field (V/m)
1				
2				
3				
4				
5				

3. Compare the variations observed in electric field strength between electrodes that are small points and between electrodes that are long parallel lines.

CONCLUSION QUESTIONS

1. Compare and contrast *electric field* and *electric potential*.

2. In general, how are electric field lines drawn in the vicinity of electric charges?

3. Define *equipotential line*. How are electric field lines and equipotential lines drawn relative to each other?

CONCLUSION QUESTIONS (CONTINUED)

4. Describe the amount of work you would have to do to move a positive charge along:

   a. An electric field line

   b. An equipotential line

5. Describe the strength of an electric field represented by electric field lines that are:

   a. Closely spaced

   b. Equally spaced

LESSON CONSUMABLE