Field Mapper Kit

PK-9023

Introduction

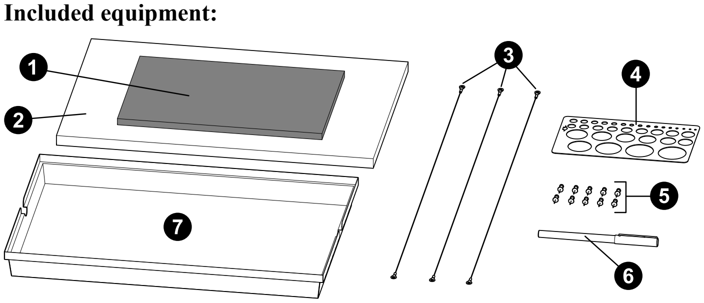
The Field Mapper Kit consists of two basic elements. The first is a carbon-impregnated paper with resistivity greater than 2 kΩ per square. This paper forms the conducting medium between the electrodes. The second element is a conductive ink dispensed from a pen. The ink is produced from silver particles in a suspension liquid. As the ink dries, the silver flakes settle on top of each other, forming a conductive path or electrodes. The resistance of the ink is between 0.03 and 0.05 Ω/cm for a 1 mm wide line.

Because the paper has a finite resistance, a current must flow through it to produce a potential difference. This current is supplied by the conductive ink electrodes, which cause a potential difference to occur across the paths. Because of the large difference between the ink's resistance and the paper's resistance, this potential drop is less than 1% of that produced across the paper. Therefore, the potential drop across the electrodes can be considered negligible.

Ideally, the potential measuring instrument used with the Field Mapper Kit would have an infinite impedance. An electrometer, such as PASCO's Basic Electrometer (ES-9078A), is ideal for this purpose. However, a standard voltmeter with a minimum 10 MΩ input impedance is sufficient. Since this impedance is at least 100 times greater than that of the paper, the voltmeter can only distort the field by approximately 1%.

Equipment

Included equipment:



1. 100× sheets of conductive paper with 23 × 30 cm grid
2. Corkboard working surface
3. 3× wires for connecting the conductive paths to each other or to a power supply
4. Circle template for drawing the conductive paths
5. 10× push pins for attaching the paper to the board
6. Silver conductive ink pen, with enough ink for about 20 ft of continuous lines
7. Plastic tray for storing the paper and other supplies

Required equipment:

- Voltmeter with input impedance of 10 MΩ or higher and full-scale range equal to or higher than the potential used across the electrodes, such as the Basic Electrometer (ES-9078A)
- Battery, DC power supply, or other potential source in the range of 5 to 20 VDC, able to supply 25 mA

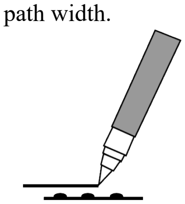
Experiment procedure

The silver conductive ink reaches its maximum conductivity after 20 minutes of drying time. For best results, plan a timetable for the experiment and schedule drawing the ink paths accordingly.

Draw the electrodes

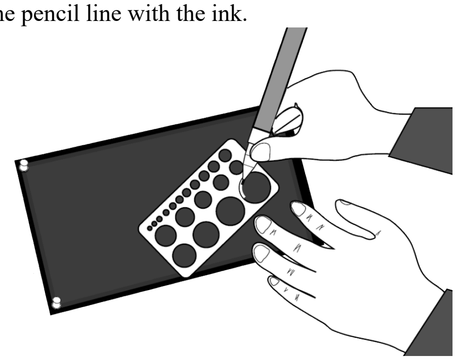
> ⓘ **IMPORTANT:** This is the most crucial part of the experiment, as well as the most difficult. Follow the steps below *carefully*.

1. On a piece of scratch paper, plan and sketch the layout of the charged paths to be studied. These paths can be any two-dimensional shape, such as lines, circles, and squares. The charged paths are the electrodes.
2. Place the conductive paper on a smooth hard surface, with the printed side facing up. Do NOT attempt to draw the electrodes while the paper is on the corkboard.
3. Shake the conductive ink pen vigorously (with the cap on) for about 10-20 seconds.
4. Remove the cap from the pen, then press the spring-loaded tip lightly down on a piece of scrap paper while squeezing the pen barrel to start the ink flowing. Drawing the pen slowly across the paper produces a solid line. The drawing speed and exerted pressure determine the path width.



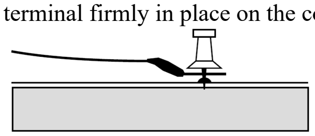
5. Once you produce a satisfactory line on the scrap paper, draw the electrodes on the black conductive paper. If the line becomes thin or spotty, draw over it again to ensure the line is solid, as a solid line is essential for good measurements.
6. Wait for the ink to dry. The line will be air dry in 3-5 minutes at room temperature but will not reach maximum conductivity until after 20 minutes of drying time.

A plastic template is included for drawing circles. To do so, simply place the template on the conductive paper and draw a circle of the desired size by tracing the pen along the edges. If desired, you may instead use the template to draw a circle with a soft lead pencil, then trace over the pencil line with the ink.



Set up the experiment

1. Mount the conductive paper on the corkboard, then secure it in place by inserting one of the metal push pins into each corner.
2. Connect the electrodes to your chosen 5 to 20 VDC potential source. To do so, place the terminal of a connecting wire over the electrode, stick a metal push pin through its terminal and the electrode into the corkboard as shown below, and connect the other end of the wire to the power supply. (Depending on your power supply, this may require additional equipment.) Make sure the pin holds the terminal firmly in place on the corkboard.



> **NOTE:** Check that the surface of the terminal which touches the electrode is clean. A dirty path may result in flawed contact.

3. Once the potential source is connected across the two electrodes, check the electrodes for proper conductivity. To do this, connect one voltmeter lead near the pushpin of an electrode, then touch the second lead to other points on the same electrode. If the electrode has been properly drawn, the maximum potential between any two points on the same electrode will not exceed 1% of the potential applied *between* the two electrodes.
4. If the voltage across any electrode was greater than 1% of the voltage applied between the electrodes in the previous step, remove the paper from the corkboard and draw over that electrode a second time with the conductive ink.

Plot equipotentials

1. Connect the ground lead of the voltmeter to one of the electrode push pins. This electrode will be the reference for the experiment.
2. Use the other voltmeter lead as a probe to measure the potential at any point on the paper by touching the probe to that point.
3. Move the probe until the desired potential is indicated on the voltmeter. Mark the paper at this point by touching the probe with a soft lead or light-colored lead pencil.
4. Continue to move the probe, but only in a direction that maintains the voltmeter at the same reading. Continue to mark points with this same reading as you move the probe.
5. Connect the points drawn in Steps 2 through 4 to form an equipotential line.

Plot field lines

Electric field lines always point from a positive charge source to a negative charge source and are always perpendicular to both the charge sources and any equipotential lines they pass through. Thus, if you have already drawn the equipotentials, you can also draw the field lines:

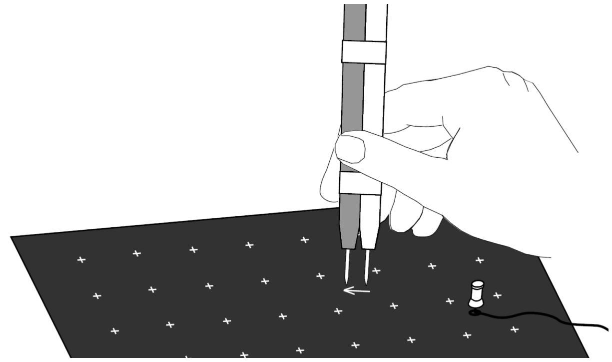
1. Draw a line extending perpendicularly out of the positive electrode.
2. Connect the line to the nearest point on the closest equipotential. Make sure that the new line drawn is perpendicular to the equipotential at this point.
3. Continue to connect the line through the nearest points on adjacent equipotentials, making sure the line is perpendicular to all equipotentials it passes through.
4. Once you reach the equipotential nearest to the negative electrode, extend the line from the equipotential to the nearest point on the electrode. The end of this final segment should be perpendicular to the surface of the electrode at the point of contact.
5. Draw an arrow indicating the direction of the field line from the positive electrode to the negative electrode.
6. Repeat Steps 1 through 5 to construct additional field lines, each time choosing a different starting point on the positive electrode.

If you have not already drawn the equipotential lines, you can also draw the field lines using the following procedure:

1. Tape the two leads of the voltmeter together. The voltmeter leads will be used to find the direction from an electrode that follows the path of greatest potential difference from point to point.

> **NOTE:** Do not attempt to make measurements by placing the leads on the grid marks of the conductive paper. Touch the leads only to the solid black areas of the paper. You may need to use a higher voltmeter sensitivity for this measurement than was used to measure equipotentials.

2. Place the non-ground voltmeter lead near one of the high potential electrodes. Place the ground lead on the paper and note the voltmeter reading.
3. Pivot the ground lead to several new positions while keeping the non-ground lead stationary. Note the voltmeter's readings as you touch the lead to each new spot on the paper.
4. Identify the direction in which the potential is highest. With the leads held at this position, draw an arrow on the paper from the non-ground lead to the ground lead, as shown below.



5. Move the non-ground lead to the head of the arrow, then repeat Steps 3 and 4 to create a new arrow, again pointing from non-ground to ground.
6. Repeat Step 5 several times. Eventually, the arrows drawn in this manner will form a field line.
7. Return to the high potential electrode, choose a new starting point for the voltmeter's non-ground lead, and repeat Steps 3 through 6 to produce a new field line. Repeat this step to produce as many field lines as needed to obtain a clear plot of the electric field surrounding the electrodes, as shown in Figure 1.

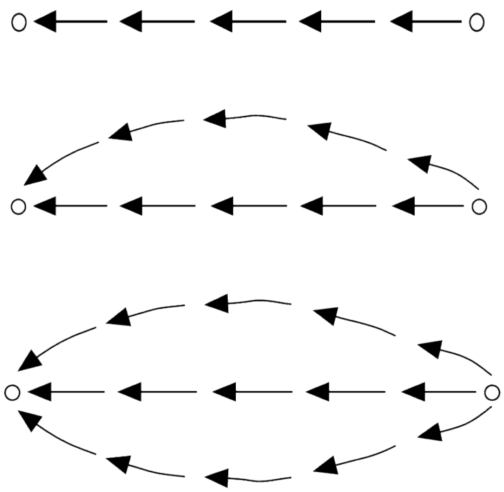


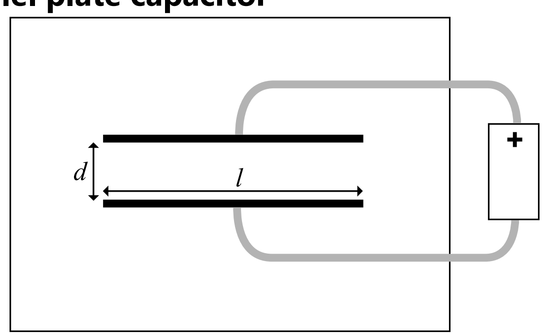
Figure 1: Constructing field lines without equipotentials.

Experiment setups

The Field Mapper Kit allows you to design almost any system of charged bodies and then map the equipotentials and field gradients produced. The following sections show some suggested experiments for mapping equipotentials and field gradients. In each illustration, the large black lines represent the electrodes drawn on the paper, while the large gray lines represent the connections to the power supply. Each section includes some questions for students to answer after making their observations.

> **NOTE:** The voltmeter connections are not shown in these illustrations, as they vary depending on whether equipotentials or field gradients are being mapped.

Parallel plate capacitor

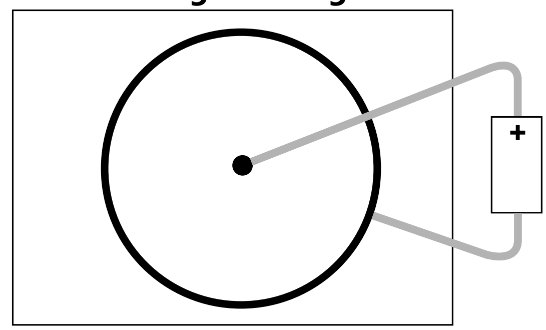


This experiment is a two-dimensional approximation of a pair of capacitor plates connected to a voltage supply. Each electrode can be thought of as a "plate" viewed edge-on.

Questions for students:

- Describe the field outside of the capacitor plates.
- How does the ratio of the plate length l to the separation d affect the fringing effect at the edges of the plates?
- What redesign of the plates, or perhaps extra electrodes, could help eliminate the fringing effect?

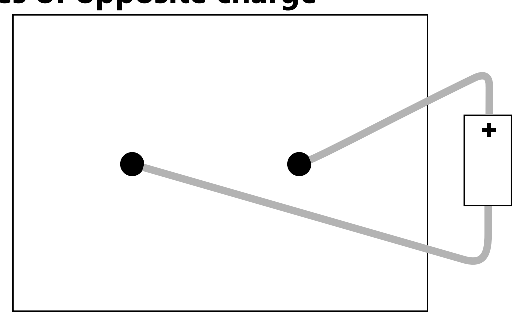
Point source and guard ring



Questions for students:

- How does the distance from the center of the point source relate to the equipotential value?
- Would this same relationship hold if the system were three-dimensional?
- What purpose does the large outer ring serve in this experiment?

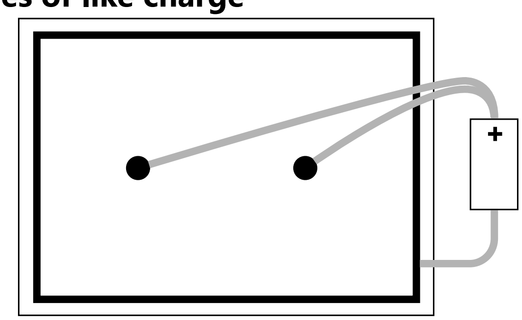
Dipoles of opposite charge



Questions for students:

- What is the relationship between the direction of a maximum value field gradient and equipotential line at the same point?
- What effect does the finite size of the paper have on the field?

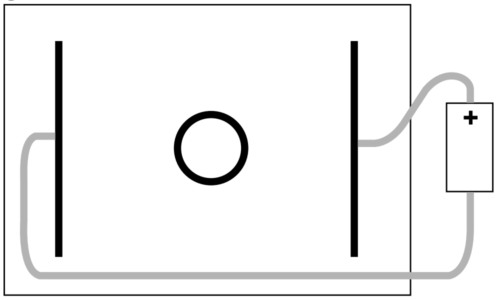
Dipoles of like charge



Questions for students:

- How does the field of this configuration compare with the field around dipoles of opposite charges?
- What distortion of the field is produced by the large electrode around the perimeter of the paper?

Floating electrode

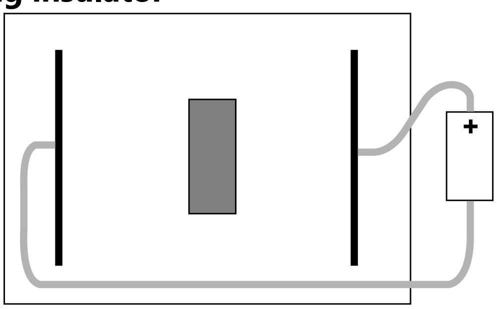


Before drawing the circular electrode, map the equipotentials of the two straight electrodes. Once you have done so, draw the circular electrode and then map the equipotentials again.

Questions for students:

- How does the circular electrode distort the field?
- What is the potential of the circular electrode? What is the potential of the area inside the electrode?
- What effect would moving the circular electrode have?

Floating insulator

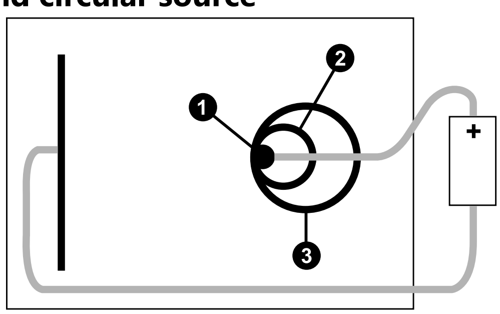


The rectangle in the above image is a rectangular region which has been cut out of the black paper and will act as an insulator. Before cutting out the section, map the equipotentials of the two straight electrodes. Cut out the rectangular section, then map the equipotentials again.

Questions for students:

- How does the rectangular insulator distort the field?
- What effect would moving the rectangular insulator have?

Line and circular source

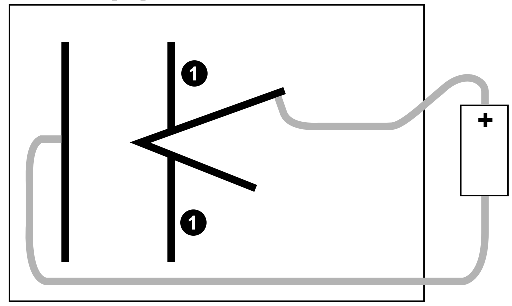


Start by drawing only the line and the point source labeled ❶. Map the equipotentials. Add the circular electrode labeled ❷, then map the equipotentials again. Finally, add the circular electrode labeled ❸ and map the equipotentials a third time.

Questions for students:

- How is the spacing of the equipotentials affected by the increasing diameter of the circular electrode?

Line and sharp point



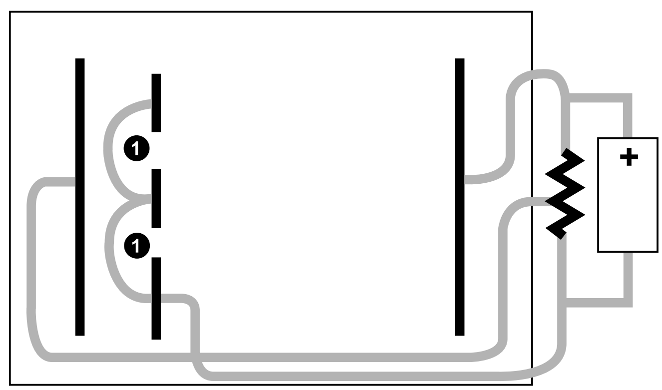
At first, do not draw the two electrodes labeled ❶. Map the initial equipotentials. Then draw the ❶ electrodes and map the equipotentials a second time.

Questions for students:

- What effect did adding the extra electrodes have on the spacing of the equipotentials (field strength) around the sharp point?
- Why did the field strength change even though the radius of the point did not change?

Triode

This experiment requires a 5K potentiometer, represented by a zigzag symbol in the figure below.



Use the 5K potentiometer to provide three potentials. Connect the three short electrodes with the wires labeled ❶. Do *not* let these wires touch the black paper except at the conductive ink electrodes.

Questions for students:

- How is the field in the area between the short electrodes affected by the potential between the short electrodes and the closer long electrode?
- Could this paper model of a triode act as an amplifying device? If not, why not?

Fluid mechanics

The Field Mapper Kit can also be used to approximately model fluid flow. Both electromagnetic potential and the velocity potential in many fluid systems satisfy the Laplace equations. Therefore, there is a direct analogy between fluid flow and electric fields. In particular, the velocity potential of an incompressible fluid where the flow is both steady and not rotational satisfies the Laplace equations. A steady flow of water is a good approximation of this type of flow. These flows are generated by *sources*, which supply fluid, and *sinks*, which absorb fluid.

We are interested in the *streamlines*, which can be thought of as lines traced out by a particular particle in the fluid. These streamlines begin at the sources and end at the sinks. To simulate such a flow using the Field Mapper Kit, we need to draw electrodes in the shape of the sources and sinks in the fluid flow to be examined. Once this is done, the electric field lines which we plot will coincide with streamlines in the fluid flow. To simulate a fixed obstruction of a specific shape in the fluid flow, cut a hole of that shape out of the conductive paper.

The diagram in Figure 2 shows a set of electrodes which simulate the flow of water through a section of pipe. In this case, the source is the straight line electrode on the left and the sink is the straight line electrode on the right. The oblong section cut out of the middle represents some obstruction within the pipe. The arrows surrounding the obstruction represent the electric field lines, which follow the paths that streamlines would follow within the pipe.

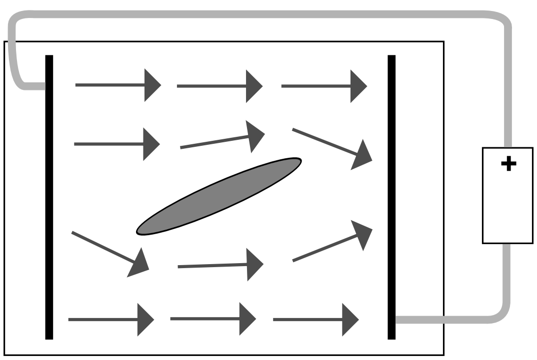


Figure 2: Example setup for fluid flow simulation experiment.

To use the Field Mapper Kit to examine fluid flows, follow these steps:

1. Draw electrodes on the conductive paper in the same shape and position as the sources and sinks in the flow.
2. Cut out sections of the conductive paper in the same shape and position as any obstructions in the fluid.
3. Connect the source and sink electrodes to the power supply. All sources should be connected to the high voltage side of the power supply, and all sinks should be connected to ground.
4. Plot the equipotentials, then draw lines perpendicular to them. Alternatively, you can pick any point and find the direction of the maximum field gradient. Either of these methods will show the direction of the streamlines at that point.

Specifications and accessories

Visit the product page at pasco.com/product/PK-9023 to view the specifications and explore accessories. You can also download experiment files and support documents from the product page.

Experiment files

Download one of several student-ready activities from the PASCO Experiment Library. Experiments include editable student handouts and teacher notes. Visit pasco.com/freelabs/PK-9023.

Technical support

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Limited warranty

For a description of the product warranty, see the Warranty and Returns page at www.pasco.com/legal.