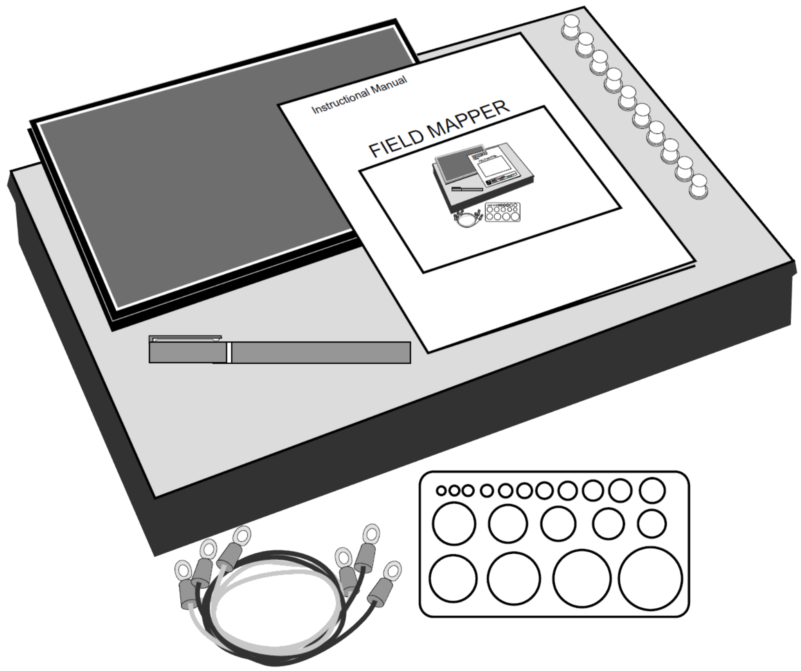
Equipotential and Field Mapper

PK-9023



Introduction

The Field Mapper consists of two basic elements. The first is a carbon-impregnated paper in the resistance range of 5 kΩ to 20 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 .03 and .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 drop to occur across the paths. Because of the large difference between the ink's resistance and the resistance of the paper, this potential drop is less than 1% of that produced across the paper. Therefore, the potential drop across the electrodes may be considered negligible.

Ideally, the potential measuring instrument would have an infinite impedance. An electrometer, such as the PASCO ES-9078A, would be optimal. However, a standard electronic 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 greatest distortion of the field which can be produced by the voltmeter is approximately 1%.

Included equipment

- 100 sheets of conductive paper with 23 x 30 cm grid
- a silver conductive ink pen for approximately 200 ft of continuous line
- a corkboard working surface
- 10 push pins for attaching the paper to the board
- 3 wires for connecting the conductive paths
- a circle template for drawing the conductive paths
- a large plastic tray for storing the paper and other supplies

Required equipment

A voltmeter that meets the following specifications is required:

- input impedance of 10 MΩ or higher
- full-scale range equal to or higher than the potential used across the electrodes

The ES-9078A Basic Electrometer is recommended.

Experiment procedure

✔ **NOTE**

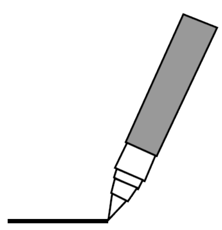
The silver conductive ink reaches its maximum conductivity after 20 minutes of drying time. For optimal results, plan the timetable for conducting the experiments and correlate drawing the conductive ink paths accordingly.

Draw the electrodes

✔ **NOTE**

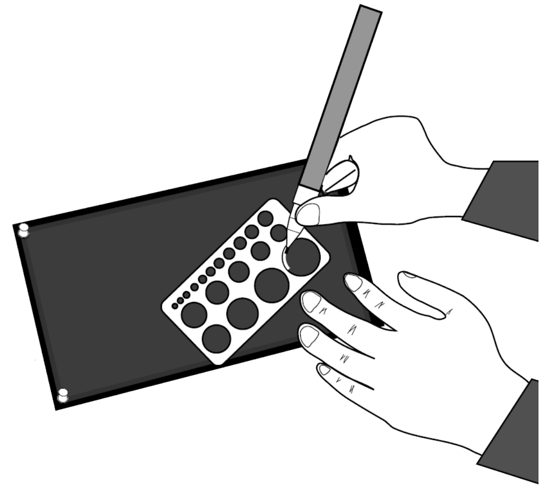
This is the most difficult and crucial part of the experiment. Follow these steps carefully.

1. Plan and sketch the layout of the charged paths to be studied on a piece of scratch paper. 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, printed side up, on a smooth hard surface. Don't attempt to draw the electrodes while the paper is on the corkboard.
3. Shake the conductive ink pen with the cap on vigorously for 10-20 seconds.
4. Remove the cap. 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. Drawing speed and exerted pressure determine the path width.



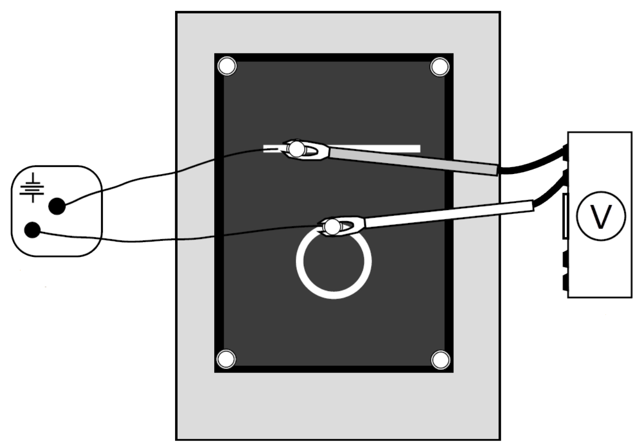
5. Once a satisfactory line is produced on the scrap paper, draw the electrodes on the black conductive paper. If the line becomes thin or spotty, draw over it again. A solid line is essential for good measurements.

   The line will be air dry in 3-5 minutes at room temperature. However, the medium won't reach maximum conductivity until after 20 minutes of drying time.
6. A plastic template is included for drawing circles. Place the template on the conductive paper and draw the circles with the conductive ink pen. If desired, you may first draw the circle template with a soft lead pencil and trace over the pencil line with the ink.



Set up the experiment

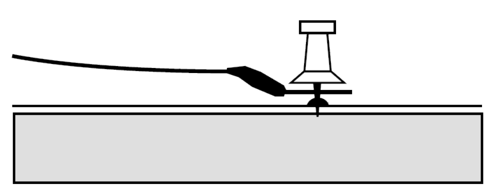
1. Mount the conductive paper on the corkboard using one of the metal push pins in each corner.
2. Connect the electrodes to a battery, DC power supply, or any other potential source in the 5 to 20 VDC range using the supplied connecting wires. The potential source should be capable of supplying 25 mA.



3. Place the terminal of a connecting wire over the electrode, then stick a metal push pin through its terminal and the electrode into the corkboard. Make certain that the pin holds the terminal firmly to the electrode. Connect the other end of the wire to the battery.

✔ **NOTE**

Check that the surface of the terminal which touches the electrode is clean. A dirty path may result in bad contact.



4. To check the electrodes for proper conductivity connect one voltmeter lead near the pushpin on an electrode. Touch the voltmeter's 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.

   > ✔ NOTE
   >
   > This test can only be made if the potential source is connected across the two electrodes.

   If the voltage across the same electrode is greater than 1% of the voltage applied between the two electrodes, remove the paper from the corkboard and draw over the electrodes a second time with the conductive ink.

Plot equipotentials

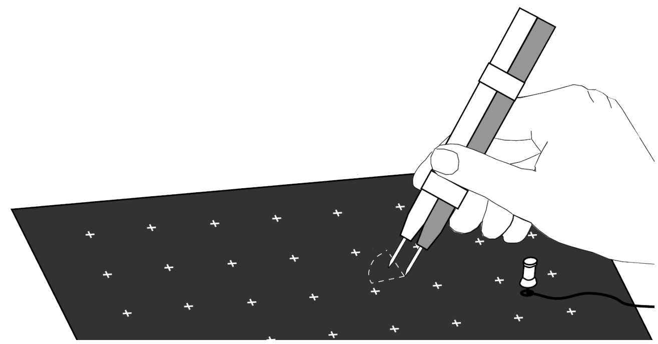
1. Connect the ground lead of the voltmeter to one of the electrode push pins. This electrode now becomes the reference.
2. Use the other voltmeter lead as a probe to measure the potential at any point on the paper by touching the probe to the paper at that point.
3. Move the probe until the desired potential is indicated on the voltmeter. Mark the paper at this point 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 these points.
5. Connect the points to produce an equipotential line.

Plot field lines

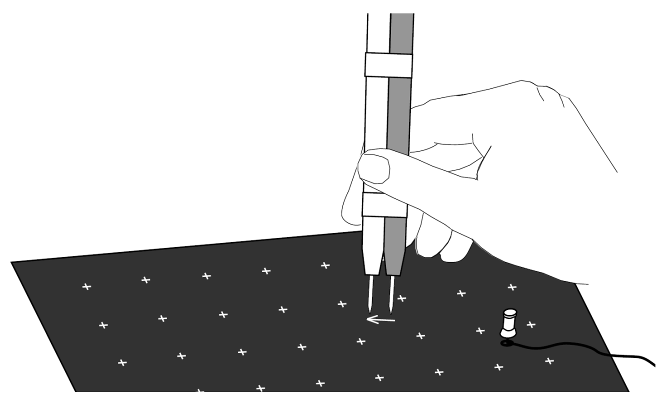
1. Tape the two leads of the voltmeter together. The voltmeter leads are used to find the direction from an electrode that follows the path of greatest potential difference from point to point.

   > ✔ NOTE
   >
   > Don't attempt to make measurements by placing the leads on the grid marks on the conductive paper. Touch the voltmeter leads only on the solid black areas of the paper. It may be necessary to use a higher voltmeter sensitivity for this measurement than was used in measuring equipotentials.

2. Place the ground voltmeter lead near one of the dipoles. Place the other voltmeter lead on the paper and note the voltmeter reading.

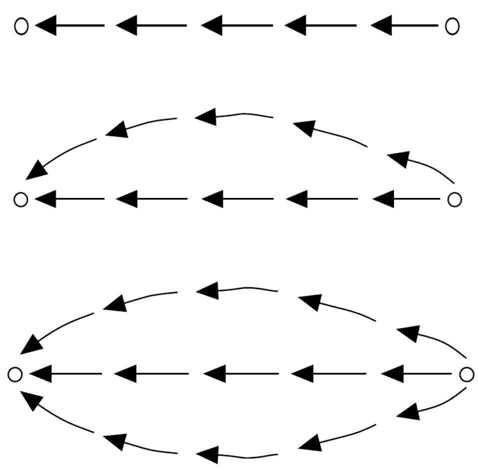


3. Pivot the lead to several new positions while keeping the ground lead stationary. Note the voltmeter readings as you touch the lead at each new spot on the paper. When the potential is the highest, draw an arrow on the paper from the ground lead to the other lead.



4. Move the ground lead to the head of the arrow. Repeat the action of pivoting and touching with the front lead until the potential reading in a given direction is highest. Draw a new arrow.

5. Repeat the action of putting the ground lead at the head of each new arrow and finding the direction in which the potential difference is highest. Eventually, the arrows drawn in this manner will form a field line.
6. Return to the dipole and select a new point at which to place the voltmeter's ground lead.
7. Again, probe with the other lead until the direction of highest potential difference is found.
8. Draw an arrow from the ground lead to the other lead, and repeat the process until a new field line is drawn. Continue selecting new points and drawing field lines around the original dipole.

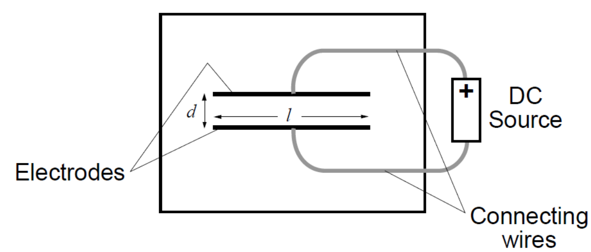


Experiment setups

The following are some suggested experiments in mapping equipotentials and field gradients. The true value of the equipment lies in its flexibility to design any system of charged bodies and then map the equipotentials and field gradients.

> ✔ **NOTE**
>
> Only power supply connections are shown in the following setups. Voltmeter connections are not shown because they vary depending on whether equipotentials or field gradients are being mapped.

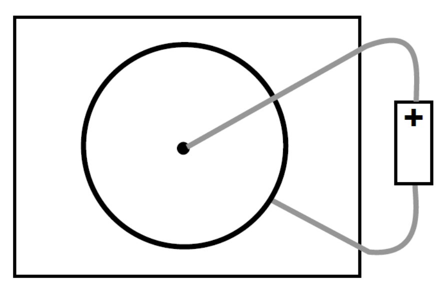
Parallel plate capacitor



Questions

- What is the field outside the capacitor plates?
- How does the ratio of the plate length (l) versus 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?

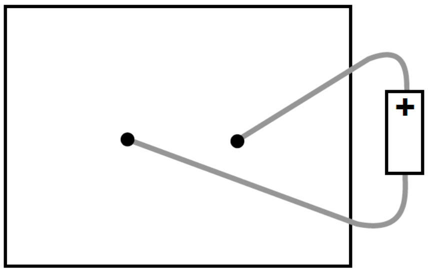
Point source and guard ring



Questions

- What relation can be derived between the distance from the center of the point source and the equipotential value?
- Would this same relation hold if the system were three-dimensional?
- What purpose does the large outer ring serve in this experiment?

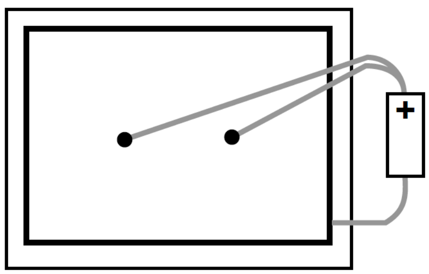
Dipoles of opposite charge



Questions

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

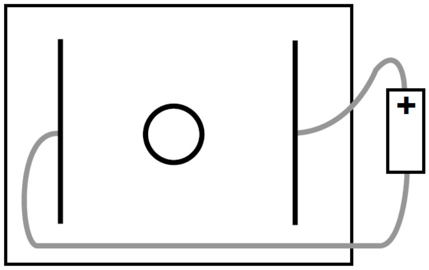
Dipoles of like charge



Questions

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

Floating electrode

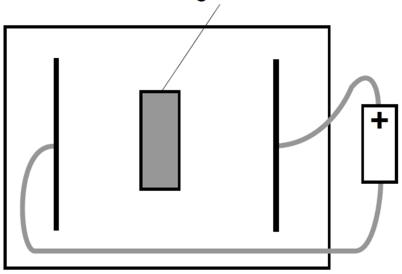


Before drawing the circular electrode, map the equipotentials of the two straight electrodes. Draw the circular electrode and again map the equipotentials.

Questions

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

Floating insulator

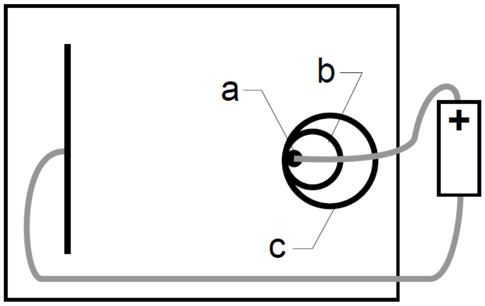


Before cutting the rectangular insulator, map the equipotentials of the two straight electrodes. Cut out a rectangular section of the paper and again map the equipotentials.

Questions

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

Line and circular source

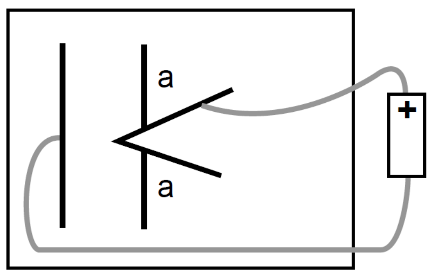


Draw only the line and point source "a." Map the equipotentials. Add circular electrode "b" and again map the equipotentials. Add circular electrode "c" and again map the equipotentials.

Questions

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

Line and sharp point



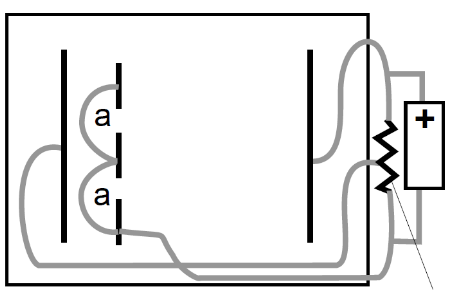
At first, do not draw the two electrodes marked “a.” Map the equipotentials. Add the electrodes “a” and again map the equipotentials.

Questions

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

Triode

> ✔ **NOTE**
>
> This setup requires a 5K Potentiometer.

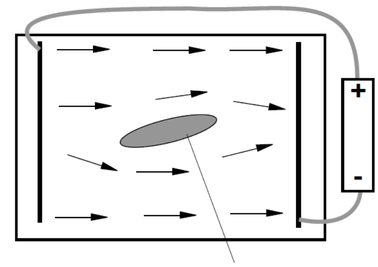


Use a 5K potentiometer to provide three potentials. Connect the three short electrodes with wires “a.” Do not let these wires touch the black paper except at the conductive ink electrodes.

Questions

- 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 can also be used to examine fluid flow. In many fluid systems, the velocity potential satisfies the Laplace equations, as does the electromagnetic potential. Consequently, 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 equation. A steady flow of water is a good approximation of this type of flow. The flow is 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. The streamlines begin at the sources and end at the sinks.

Turning to the Field Mapper, we need to draw electrodes in the shape of the sources and sinks in the fluid flow to be examined. Then the electric field lines which we plot coincide with the streamlines in the fluid flow. If there is some fixed obstruction in the fluid flow, we can represent it by cutting the same shape from the conductive paper. The schematic drawing shows a fluid flow that is analogous to the flow in a section of pipe. This source is a straight line at the left, the sink is a straight line at the right. The tear-drop-shaped section cut out of the middle is some obstruction. The field lines are the corresponding streamlines.

To use the Field Mapper 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 the obstructions in the fluid.
3. Connect a battery between the sources and sinks. All sources should be connected to the same side of the battery. All sinks should be connected to the opposite side.
4. Plot the equipotentials and draw lines perpendicular to these. You can also pick any point and determine the direction of the maximum field gradient. This is the direction of the streamlines at that point.

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**.

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.

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