Concepts in Physics
Lab 6: Equipotential Lines

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Introduction

We will play around with electrical energy, seeing how very abstract, invisible concepts like electrical energy can become things we can measure and graph in the real world. There's no point in talking about force fields and such in science fiction if we can't whip a few up in the lab.

You will learn how to find *equipotential lines* in a tray of tap water. An equipotential line is a collection of points where each point has the same voltage as every other point. For example, the set of all points which have a potential of 4 volts is an equipotential lines.

Voltage is closely related to electrical energy; all electrons on your 4 volt line would have the same electrical energy. Voltage is the electrical energy of an object (in joules, J) divided by the charge of the object (in coulombs, C). The unit of electric potential (or voltage) is J/C = volts, V.

Think of voltage as being similar to gravitational energy. An example of an equipotential surface for gravity is, assuming the ground is flat, all points 2 meters above the ground, since a mass of 1 kg would gain the same amount of energy if it fell from anywhere on that surface to the ground.

We will map out some of these equipotential lines in a shallow tray of water, for three different situations:

1. Two point sources, like two point charges
2. Two parallel plate sources with a circular conductor between them,

3. One more different arrangement of your choice.

Equipotential lines behave in a certain way in the vicinity of a *source*—any distribution of charges—and in the vicinity of a conducting surface:

- Near a source, the equipotential lines are parallel to the surface of the charge distribution—just like surfaces in space with equal gravitational energy are parallel to the planet surface.
- Near a conducting surface, the equipotential lines are again parallel to the conducting surface.

Goal

You will make maps of equipotential lines, for three different set ups, by measuring the value of the voltage at various points for each set up.

In the first case, you will have one point source at 0 V and another point source at about 10 V (very roughly; it depends on the power source I set up for you), and you will map the equipotential lines in the region containing those two sources.

In the second case, you will have one source consisting of a long plate of metal at 0 V, and another source consisting of another long plate of metal at about 10 V, parallel to the first piece of metal. Between the two pieces of metal, you will place a conducting ring, which will not be connected to any voltage source. You will map the equipotential lines in the region containing the two plates and the conducting ring.

In the additional cases, you will map the field for a source or sources of your choosing.

Procedure

The source of voltage is a function generator or signal generator. It will generate an adjustable alternating (AC) voltage of about 0 to 10 volts. You will measure voltage with a digital voltmeter.

1. Place a piece of graph paper under the glass tray and fill the tray with about an inch of water. Place another, identical, piece of graph paper

next to the tray. You will take your measurements in the tray above the first piece of graph paper. You will draw your maps on the second piece of graph paper.

2. Set your function generator to produce a sine wave at a frequency of about 1 kHz, with a voltage of about the maximum possible (around 10 V), and call that value V_0. I will come around and show you what to do.

Activity 1: Two Point Sources

1. Obtain two point source electrodes and one test electrode. Place the point source electrodes about 12 centimeters apart in the water on the line down the middle of the long axis of the graph paper. Mark these points on your own graph paper. It will be easier if you graph everything to scale.
2. Attach the positive output (+ or red) of the function generator to one point source electrode and the negative output (−, ground or black) to the other. Use banana wires and alligator clips as necessary.
3. Attach the positive input (+ or red) of the digital voltmeter to the test electrode and the negative input (−, ground or black) to the negative source electrode.
4. Mark two sheets of graph paper with the (same) positions of the two point sources, and place one sheet under the tray, and the other sheet next to the tray. Make sure the point sources are in the correct places.
5. Place the test electrode into the water (make sure you hold it straight up and down, not tilted). The voltmeter should read a value between 0 and V_0. As you move the test electrode around in the water the voltage should change. You are sampling the voltage of various points in the water. What you are actually doing is measuring the voltage between a point in the water and the negative source electrode. If you measure points near the negative source electrode you will get values close to 0 volts. If you measure points close to the other electrode you will get values close to V_0. Try it. (Note: Only read the voltmeter to $\pm.1$ V; it will fluctuate too much at the .01 V place.)

6. Pick about 6 or 7 voltages spread about evenly between 0 and V_0, and (for each of those voltages) find enough points in the tray which are at that voltage to define a shape for that equipotential line. Remember that "at that voltage" only has to be to within $\pm .1$ V.
7. Using your measurements, draw a careful map of the equipotential lines. Your map should include the sources, should show each point you measured, and should show about 7 lines of equipotential inferred from those points. If you feel you need to take additional measurements in certain areas to make the pattern clear, then do so. Label each point, each line, and the two sources with their actual measured voltages (to within .1 V).

Activity 2: Two Parallel Plates With Circular Conductor

1. Obtain two flat long bars of metal. Remove the two source electrodes, and replace them with the plates, placed parallel and as far apart as possible. Use alligator clips to make electrical connections between the plates and the function generator and the voltmeter.
2. Place a conducting ring midway between the plates. Do not connect it to anything.
3. The test electrode will be connected to the positive input of the voltmeter and will be used to map out the lines exactly as before.
4. On two sheets of graph paper mark the (same) position of the plates and the conducting ring. Place one sheet under the tray (with the plates and the ring in the appropriate places), and place the other sheet next to the tray.
5. Proceed as in part 1 to map out equipotential lines. Label each of the lines, the two plates, the ring, and the inside of the ring with their respective voltages.

Activity 3: Additional Charge Distributions

Using the same basic technique as in activities 1 and 2, make field maps for one more charge distribution. All the charge distributions you map should be different. Here are some suggestions for additional charge distributions to try after parts 1 and 2:

- A *line* of one charge and a *point* of the opposite charge,
- Two *non*-parallel lines of opposite charge,
- A conducting *ring* of one charge, and one or more lines of the opposite charge,
- Something else you think of (consult with instructor first).

As you do the experiment, check on the value of V_0 to make sure it hasn't drifted. If it has, readjust it accordingly.

To hand in

A equipotential line graph for each configuration you examined.