

Electric Field Mapping

Equipment: mapping board, U-probe, 5 resistive boards, templates, 4 long leads, Phywe 07035.00 voltmeter, DC wall voltage output, 3 pieces of paper

Precautions

1. Before turning the mapping board over, remove voltage leads from the board.
2. Grasp the diagonal corners of the mapping field board to turn it over. Please do not grasp edges of the mapping board, or you can break the two wires underneath the board edges.
3. Handle the resistive boards carefully by the edges, for it is easy to scratch the resistive coating.
4. Be aware of the orientation when installing the resistive boards.

1 Theory

The force between charged particles is attributed to an electric field \vec{E} which has the dimensions of force per unit charge. A charge q when in the presence of an electric field produced by other charges experiences a force $q\vec{E}$. Voltage (V), or potential (these two words are equivalent and interchangeable) is another useful quantity to keep in mind. It has the dimensions of work per unit charge, or in S.I. units, joules/coulomb (J/C). The potential between two points **(a)** and **(b)**, or at **(a)** with respect to **(b)**, is given by $V_a - V_b = V_{ab} = \int_a^b \vec{E} \cdot d\vec{l}$, where $d\vec{l}$ is a differential displacement. If a surface is constructed so that it is always perpendicular to the electric field \vec{E} , the potential difference between any two points on the surface will be zero, and the surface will have a constant voltage. This type of surface is called an equipotential surface.

A voltmeter is an instrument that has two metal probes. If the two probes are put in contact with any two conductors, the voltmeter will provide the voltage or potential between the two conductors. However, in a region of vacuum or air the voltmeter cannot provide voltage because neither vacuum nor air can supply the necessary charge or electrical current necessary to make the voltmeter work. It can be shown that if perfect conductors are embedded in a homogeneous resistive medium, then the electric field and equipotentials are the same as in vacuum, which is the technique you will use in this experiment. "Electrodes" are painted on the flat resistive boards using highly conducting paint. Voltage differences are

applied to the electrodes, and the equipotential surfaces in the resistive medium are found by using a voltmeter.

This experiment is two, not three, dimensional, as the conducting board is a flat thin sheet. Therefore, the equipotentials that you measure will be lines, not surfaces, but equivalent to those that would be obtained if the electrodes extended to infinity both into and out of the resistive board, and the material between the electrodes was a uniform homogeneous isotropic dielectric or resistive medium.

2 Description of the Mapping and Resistive Boards

The resistive boards are semi-insulating and have patterns painted on them with a highly conducting paint. Each painted area (“electrode”) has a constant potential. When the positive and negative terminals of the power supply are each connected to one of the electrodes, every part of the resistive board attains a potential that depends on the shapes, orientations, and positions of the electrodes. The potential of any point on the board can be measured with a voltmeter. There are five patterns available on resistive boards (see Fig. 1). These patterns are

1. Two small circles
2. Two parallel rectangles
3. A small circle and a rectangle
4. A small circle and a “L”
5. Two small circles which are connected to the voltage source, and a conducting circle and a non-conducting circle

In this experiment, your TA will decide which three boards to use. Remember, the equipotentials you measure are the same as if the electrodes extended into and out of the board and that everywhere the inter-electrode material has a dielectric or resistive medium. Board 1 simulates two oppositely charged long wires that are in vacuum. This is the simplest situation, as you have a pretty good idea of what the equipotentials look like. Board 2 simulates capacitor plates. It is interesting to see what the fringing field lines look like. Boards 3 and 4 are variations of these ideas. Board 5 is the most complex; it is interesting to see what happens to electric field lines when a conducting body or an insulating body is placed between two charges. Will the field lines pass through the bodies, or go around them? Explain.

3 General Procedures

The electric field mapping apparatus is designed so that the resistive board is mounted on the bottom (see Fig. 2).

- Remove the two leads from the battery terminals of the resistive board if they are attached.
- Hold the mapping board by two diagonal corners and turn it over so that the legs jut upward and the resistors can be seen. (If you hold the apparatus along the edges, it is all too easy to break a wire underneath.)
- Once turned over, hold the resistive board carefully by the edges and place the resistance board on the mapping board with the pattern side visible, so that the contact screws of the mapping board go through the two holes in the resistive board. See figure 2.
- Fasten the board to the apparatus by tightening the screws by hand until they are snug, but not excessively tight.
- Now turn the apparatus right side up so that the two electrical binding posts and rubber knobs are visible. Lay a piece of paper on top of the apparatus. Push down on the apparatus board to raise the four rubber knobs above the board, and insert the corners of the paper under the knobs.
- A plastic template is provided to place over the paper by fitting it into two top alignment pins. The template serves as a guide for whichever electrode pattern is being used. Place the appropriate template over the paper, and trace the outlines of the electrodes.
- Then very carefully, remove the template, while trying not to move the paper. Now you will have an idea of where your electrodes are. For a configuration with both conductors and insulators, you must label which is which.
- In order to make an electrical contact between the board and voltmeter, the end of the U-probe with an electrical ball on it is passed under the apparatus and pressed against the resistive board. The other end of the U-probe goes over the mapping board and has a hole that allows you to make a pencil mark on a piece of paper, if aligned vertically. See figure 3.
- You will be scanning the probe over the surface to find locations that have the desired potential, and marking those points. By connecting the dots corresponding to the same voltage, you form an equipotential line on the paper. The 7 equipotentials that are mapped out are the potentials at the 7 jacks.

To make the measurements more sensitive, the mapping board is designed with a chain of 8 equal resistors between the two points where voltages are applied. The chain divides the voltage difference into 8 equal intervals. There are 7 jacks that allow you to access these voltages. One lead of the voltmeter is connected to one of these resistor jacks, and the other lead is attached to a "U-probe," which is a very long "U-shape." By plugging the negative voltmeter lead into one of the resistor jacks, you can use the U-probe to search for points corresponding to zero on the voltmeter. **A reading of zero means the point is at the same potential as the jacks between the resistors you choose.** Depending on the

direction of the voltage being applied, it is wise to start at the resistor jack labeled either E1 or E7.

To get consistent results with the U-probe it might be necessary to squeeze the arms of the probe a bit so that the metal half-sphere on one arm of the U makes good electrical contact with the resistive board. Please don't overdo it. Squeeze just enough so that the meter reading is stable.

You can then repeat the experiment for all 7 resistor jacks to create equipotential lines. Along an equipotential line is it possible to move a charge with no loss of energy? Explain.

4 Mapping the Equipotential Lines

After you're done setting up the resistive board, set the voltmeter to either 3 or 10 volts DC, and plug the positive and negative electrode leads from the DC wall output into the terminals of the resistor board (See Fig. 4). Start with the (negative) lead of the voltmeter plugged into the first resistor jack ("E1") or ("E7"). **Use the probe to locate points of zero potential. A potential equal to the voltage drop over the resistor(s). In other words when the voltage meter reads 0 then, mark a point on the paper.** When you have finished searching for points from that resistor jack, connect the points in a physically sensible way to make an equipotential line. Repeat the procedure for more of the resistor jacks. You may also make equipotential lines using non-zero voltages. For example, if you wish, you could have an equipotential line at 5 V. Just make sure you do not change your resistor jack or chosen voltage while you are making an equipotential line.

Use the boards your TA told you to use. Try to explain the results of your lines. Don't worry about minor wiggles. The resistive coating on the boards is not perfect.

Answer the following questions about the principal features of your lines of constant potential ("equipotentials").

1. Where are the equipotential lines closest together and where are they farthest apart? Why?
2. Do any of your equipotential lines cross? Do you think it is possible for equipotential lines or surfaces to touch or cross?
3. Explain the direction of the equipotential lines near the edges of the electrodes?

5 Electric Field Lines

Electric field lines are drawn so that they are always parallel to the electric field and their density is proportional to the magnitude of the electric field. Draw electric field lines perpendicular to your equipotential lines, putting lines closer together where the electric field is stronger. Include arrows on the field lines to show the direction of the electric field. The direction can be inferred from the polarity of the connections going to the electrodes.

Answer the following questions.

1. If you reversed the polarities of the electrodes, how does the patterns of electric potential and field lines change?
2. When is it possible for electric field lines to cross? Explain.
3. What features of the equipotential map indicates the location of where the electric field is the strongest? Why? Is the electric field strongest where you expect it to be?
4. Explain in your own words why a surface that always has \vec{E} perpendicular to it is an equipotential.

6 Finishing Up

Please straighten out the equipment. Also, tell your TA if there were any issues with the equipment. Cheers.

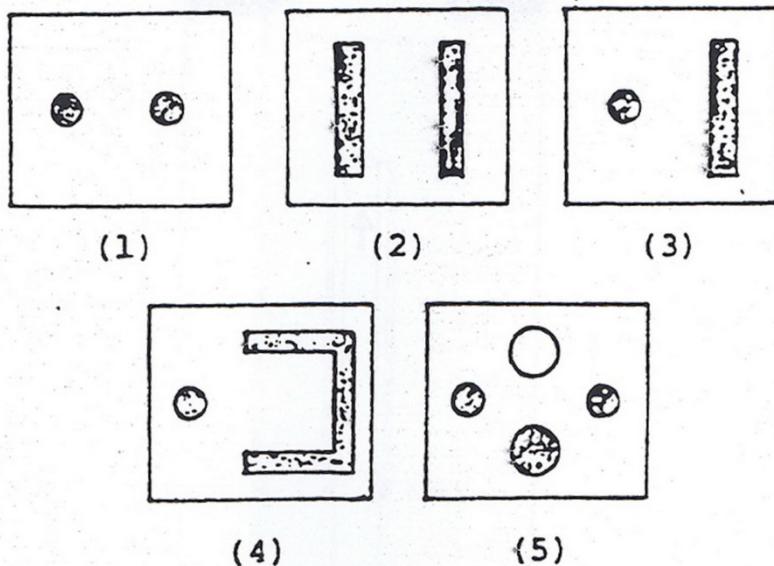


Figure 1: Electrode patterns painted on the resistive boards.

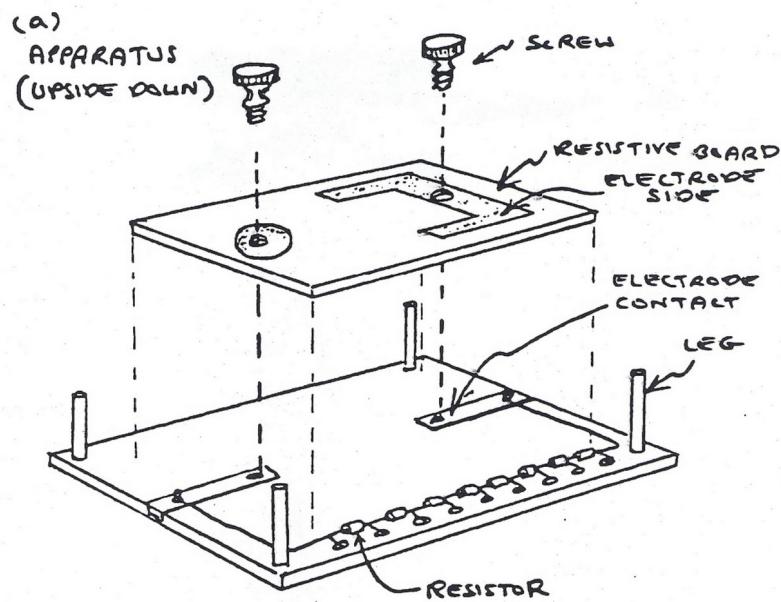


Figure 2: Mounting the resistive boards.

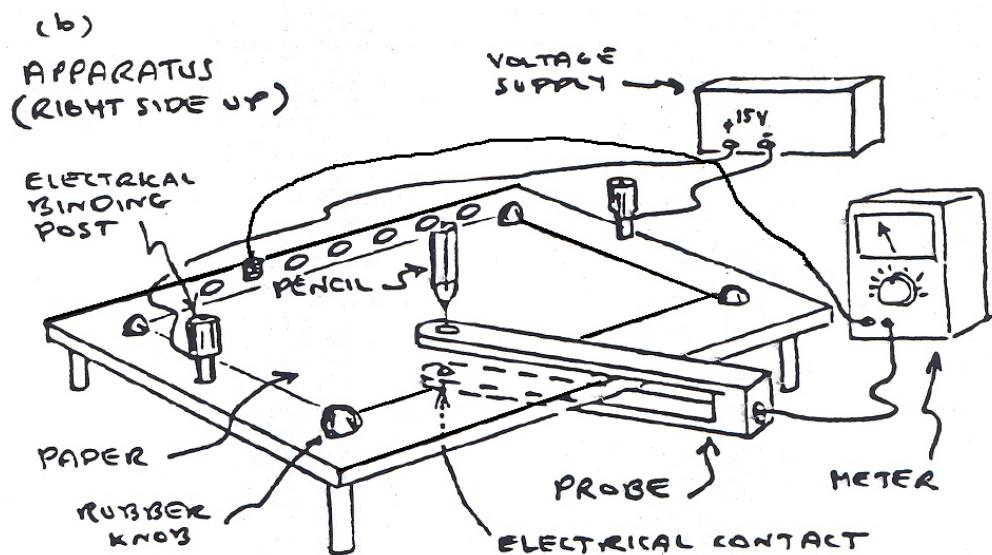


Figure 3: Mounting the resistive boards.

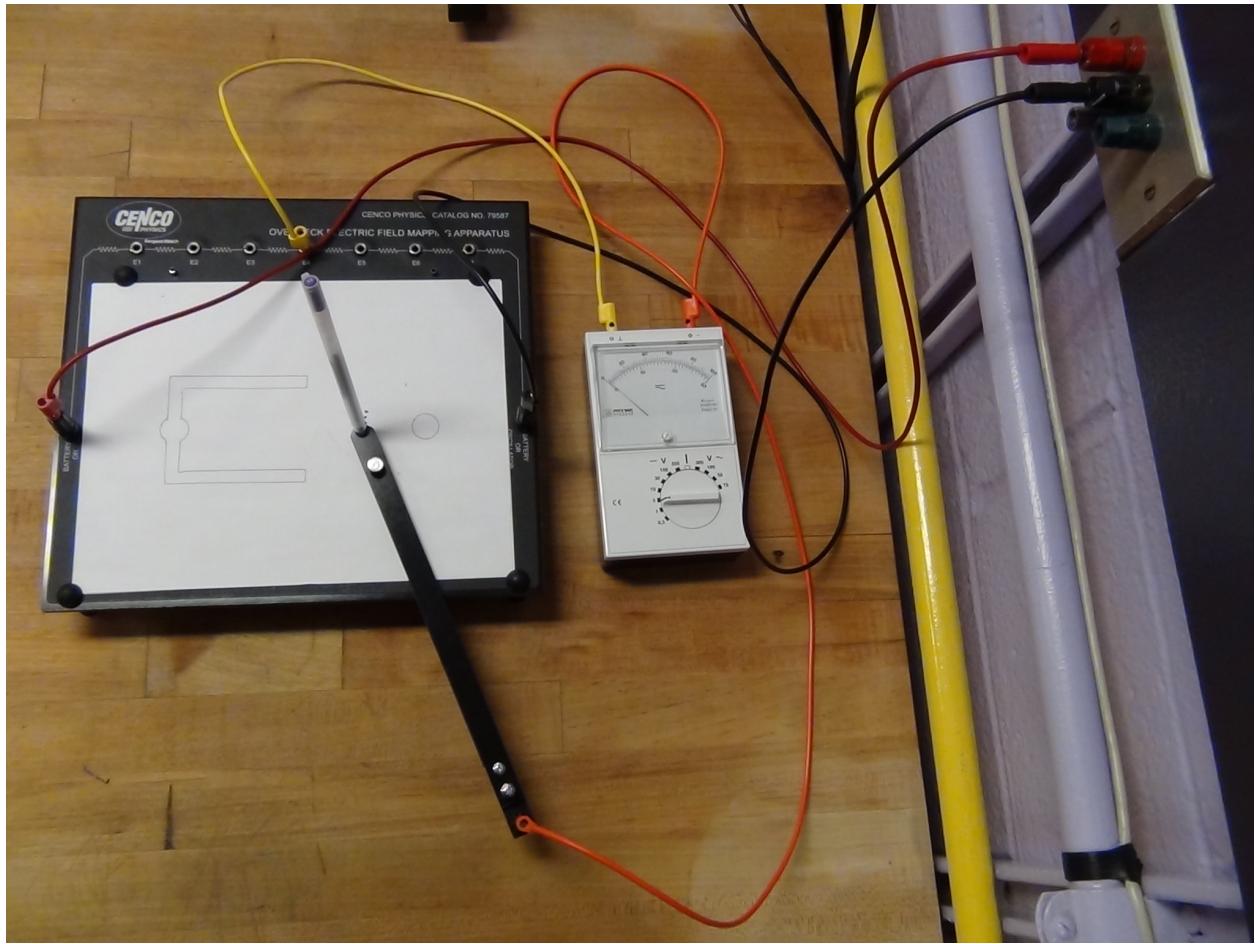


Figure 4: Setup of the board plugged into the DC wall output