

Electric Field Mapping

Equipment: mapping board, U-probe, 5 resistive boards, templates, knob adjustable DC voltmeter, 4 long leads, 16 V DC for wall strip, 8 1/2" X 11" sheets of paper

Reading: Topics of electric fields.

Precautions

1. Before turning mapping board over, remove voltage leads from board.
2. Turn mapping board over by grasping two diagonal corners of board. Please do not grasp edges of mapping board, which may break a wire underneath the board near the edge.
3. Handle resistive boards carefully by edges. It is easy to scratch the resistive coating.
4. During the experiment, keep checking that the knurled nuts, particularly the one with the U-probe, are tight.

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 $q\vec{E}$. Another useful quantity is the voltage or potential (these two words are equivalent), which have the dimensions of work per unit charge, or in S.I. units, joules/coulomb (J/C). This last combination of units, J/C, is called the volt (V). The potential between two points a and b, or the potential at a with respect to b, is given by

$$V_a - V_b = V_{ab} = \int_a^b \vec{E} \cdot d\vec{\ell},$$

where $d\vec{\ell}$ is a differential displacement. If a surface is constructed so that the electric field \vec{E} is always perpendicular to it, the potential difference between any two points on the surface will be zero. A surface which has a constant voltage is called an equipotential surface. If several charged conductors exist in a region of vacuum or air, electric field lines and equipotential surfaces can be constructed.

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 give the voltage or potential between

them. The voltmeter will not give, however, the voltage between two points in vacuum or air because vacuum or air cannot 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, the electric field and equipotentials are the same as in vacuum. This is the technique used in this experiment. Highly conducting paint is used to paint “electrodes” on a flat resistive board. Voltage differences are applied to the electrodes and the equipotential surfaces in the resistive medium, and are found using a voltmeter.

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

2 Description of Mapping and Resistive Boards

The resistive boards are semi-insulating and have patterns painted on them with highly conductive paint. Each painted area (“electrode”) has a constant potential. When the positive terminal of a power supply is connected to one of the electrodes and the negative terminal of the power supply connected to another electrode 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 “ \sqcup ”, and
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 select 4 patterns for you to draw. (Patterns 1 and 2 are similar, but not identical, to diagrams you can find in any physics II textbook.) Remember, the equipotentials you measure are the same as if the electrodes extended into and out of the board and everywhere within the dielectric or resistive medium.

Board 1 simulates two oppositely charged circles that are in vacuum. This is the simplest situation, as you have a pretty good idea 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, or what?**

The electric field mapping apparatus is designed so that the resistive board is mounted on the bottom (see Fig. 2). The mapping board has a chain of 8 equal resistors that divide the voltage difference that is applied to the two electrodes 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 voltmeter lead is attached to a U-probe. One end of the U-probe has an electrical ball that is pressed against the resistive board on the underside of the mapping board. The other end of the U-probe is on the top of the mapping board and has a hole that allows you to make a pencil mark on a piece of paper. The 7 equipotentials that are mapped out are the potentials at the 7 jacks.

3 General Procedures

- Remove the two leads from the “Bat or Osc” 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 (Fig. 2a). (If you hold the apparatus along the edges, it is all too easy to break a wire underneath.)
- Holding the resistive board carefully by its edges, place it on the mapping board with the pattern side visible. Mount the resistive board as illustrated in 2a. Make sure the two holes in the resistive board line up with the holes on the mapping board.
- With the 2 large thumb screws, fasten the board to the apparatus. The large thumb screws should be tightened 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 4 rubber knobs are visible.
- Lay a piece of paper on top of the apparatus by pushing down on the apparatus board. This raises the 4 rubber knobs above the board. Next, insert the corners of the paper under the 4 rubber knobs.
- Wire up the electric field mapping as illustrated in Figure 2.
- Plug the positive and negative electrode leads into the 16 V wall strip (See figure 2).
- Set the voltmeter to the 5 volt scale.
- A plastic template is provided to place over the paper by fitting it onto the alignment pins. The two alignment pins are located on the top of the electric field mapping board apparatus. The template serves as a guide for whichever electrode pattern is being used.
- Place the template over the paper, and trace the outlines of the electrodes. Very carefully remove the template, 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.

- You will be making marks on the paper using the U probe. The “U” probe for the voltmeter is a very long “U-shape”, with one arm passing under the apparatus to make an electrical contact between the resistance board and voltmeter and the other arm passing on top having a hole for a pencil to pass through to mark the paper.
- Check that the hole on the U probe is aligned vertically so that when you scan the probe over the surface and find a location having the desired potential, a mark can be made at that location on the paper. By connecting dots corresponding to the same voltage, you form an equipotential line on the paper.
- To get consistent results with the U-probe it will 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.

General comments on measurements

To make the measurements more sensitive, the board is designed with a chain of resistors between the two points where the voltages are applied. 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. You can then repeat the experiment for all 7 resistor jacks to create equipotential lines which are equally spaced in potential. An advantage of this system is that since you are looking on the voltmeter for a value of zero instead of a high value, you can switch the voltmeter to a lower more sensitive scale.

4 Drawing Equipotential Lines

Start with the black(negative) plug of the voltmeter plugged into the first resistor jack (“E1”). Use the probe to locate points of zero potential (i.e. a potential equal to the voltage drop over the resistor(s)). 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 boards 3-5 in that order. Board 5 is best done last as it is the most interesting and complex. Try to explain the results. 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?

2. Do any of your equipotential lines cross? Do you think it is possible for equipotential lines or surfaces to touch or cross? (Hint. In your text book, see if you can find a figure with the equipotentials of two positive point charges.)
3. What is 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 the polarities of the electrodes are reversed, how do the patterns of electric potential and field change?
2. Is it possible for electric field lines to cross? Explain.
3. What feature of the equipotential map indicates where the electric field is 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 leave the bench as you found it. Thank you.

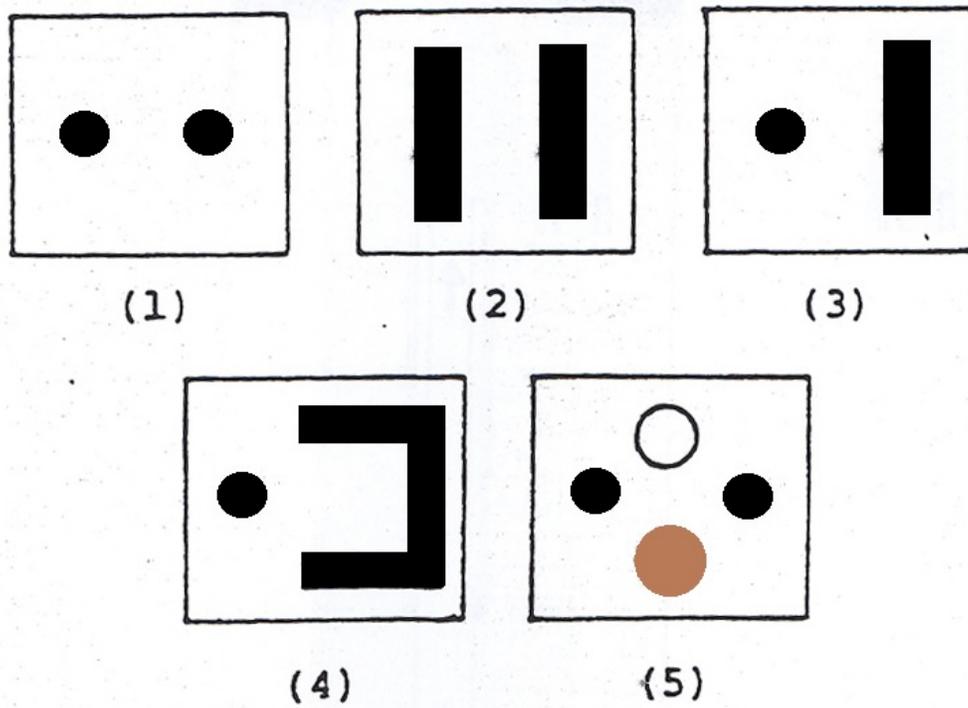
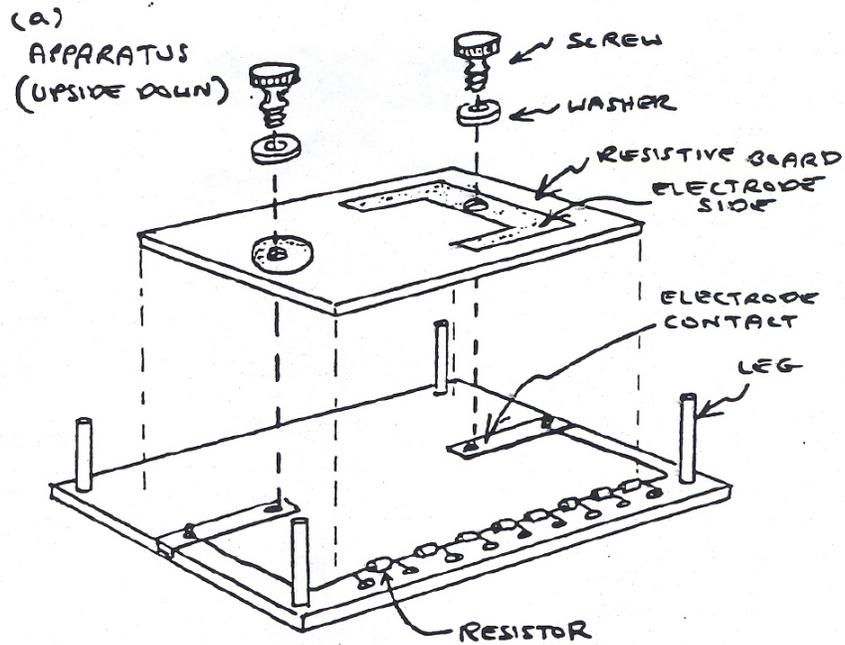


Figure 1: Electrode patterns (in black) painted on the resistive boards.



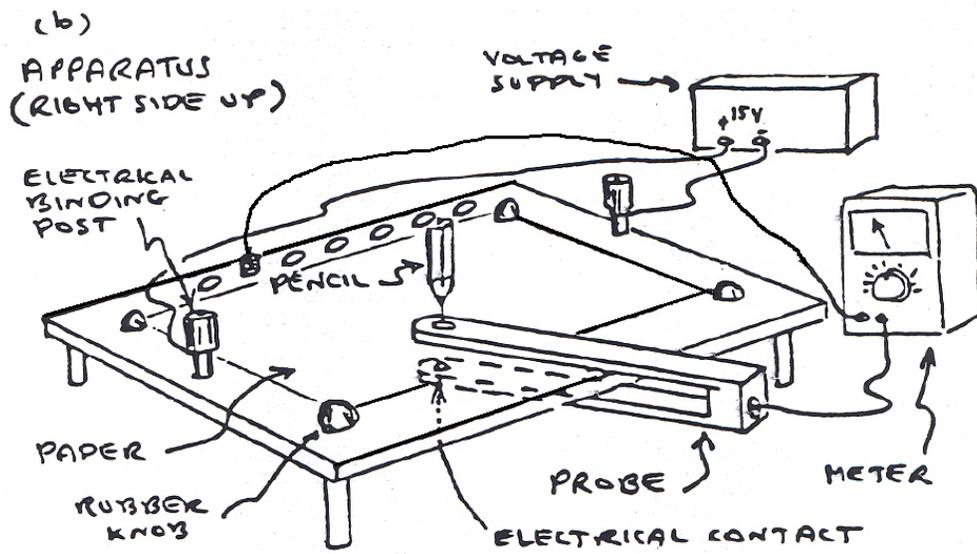


Figure 2: (a) Method for safely mounting the resistive boards. (b) Arrangement for recording equipotential lines with a pencil