Physics 261
In-class Laboratory

Electric Field Mapping

Background:

An electric field is a vector field that is produced by an electric charge. The source of the field may be a single charge or many charges. To visualize an electric field, we use lines of force. The arrows on the lines point in the direction of a force felt by a unit positive charge placed into such a field, so that lines of force leave positive charges and enter negative ones for simple one charge configurations such as seen in (Figure 1.1)

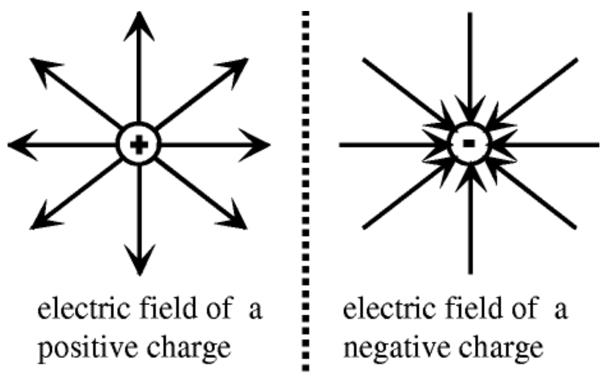

Figure 1.1: Electric fields of positive and negative charges**.**

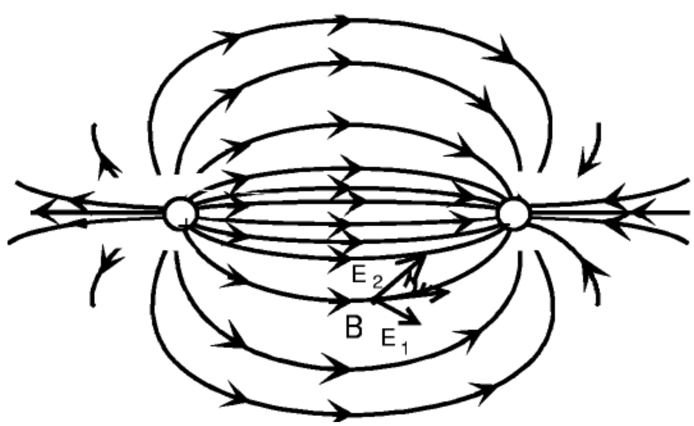

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Figure 1.2: Electric Field near two equal charges of opposite sign

If the charge configuration has more than one member as in the configuration in Figure 1.2, then the vector properties of the electric field must be considered. Here we see two charges and want to see what would happen to a positive test charge introduced into the system. Let's imagine the charge is introduced at point B. Generally, we must use vector analysis to predict the force on the charge. Let E_1 be the force felt by the test charge because of the presence of a like unit positive charge. Let E_2 be the attraction felt by the test charge to the unit negative charge. Here, using vector addition, the electric field line is calculated for this system of charges. The resultant, r, is tangent to the electric field lines, thus the lines can be drawn in by realizing the resultant at each point in the diagram, or several points and sketching the electric field lines from these observed resultant vectors.

To maintain the charge at a specific position in the electric field or move it against the field requires an expenditure of energy. The work done to bring a charge from infinity to a particular point in the field is called potential energy. It would become kinetic energy if the charge were free to move. The electric potential energy, sometimes just called 'potential' is the energy per unit charge. Lines of equal potential define a force field, as lines of force are perpendicular to such potential lines (Figure 1.3). This is because when a charge is moving along an equipotential line no work is done, and thus the electric field cannot have a component in this direction. If potentials can be measured and equipotential lines drawn, electric fields can be mapped. (Remember both potential lines and lines of force do not actually exist but are simply mental devices for thinking about force fields.)

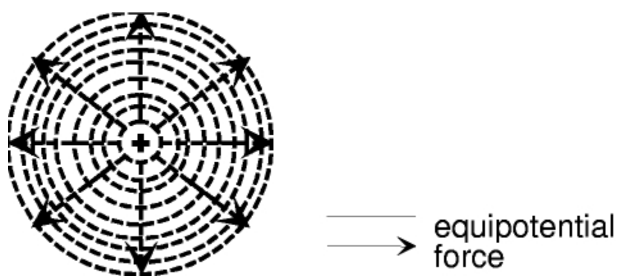


Figure 1.3: Equipotential lines, and lines of force for the field of a positive point charge

The procedure below gives details about the simulation and the apparatus used in this experiment to map out equal potential lines, and thus the electric field. Try to anticipate the features of the equipotential lines within your group before using what is known about electric fields and equipotential surfaces. Use the ideas presented above to predict the field geometry from the plate geometry.

Experimental Method:

Students will first explore the electric field around point charges, lines of charges, and parallel plates using the simulation: http://www.falstad.com/emstatic/index.html. Students will then assemble the physical experimental equipment to study either the faraday pail or the insulator and conductor plates.

To study the equipotential lines near a set of charged electrodes surrounded by air (or vacuum), in this lab **we study an equivalent problem**: the equipotential lines near a set of charged electrodes surrounded by a conducting medium instead. The disadvantage of this equivalent system is that current must be **constantly supplied** to replenish the charge flowing out of the positive electrode through the medium, while the advantage is that we can measure the potential around the electrode using an ordinary voltmeter. **One can show that the same general equations for potential apply to both systems making this laboratory system equivalent to the original problem.**

Figure 1.4: Plate Geometry for Overbeck Electric Field Mapping Apparatus

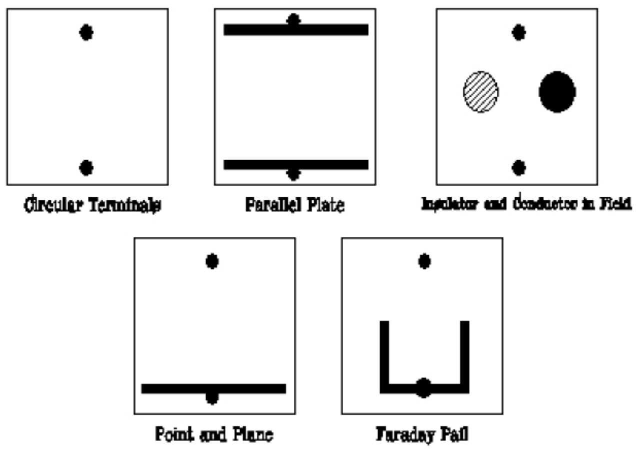
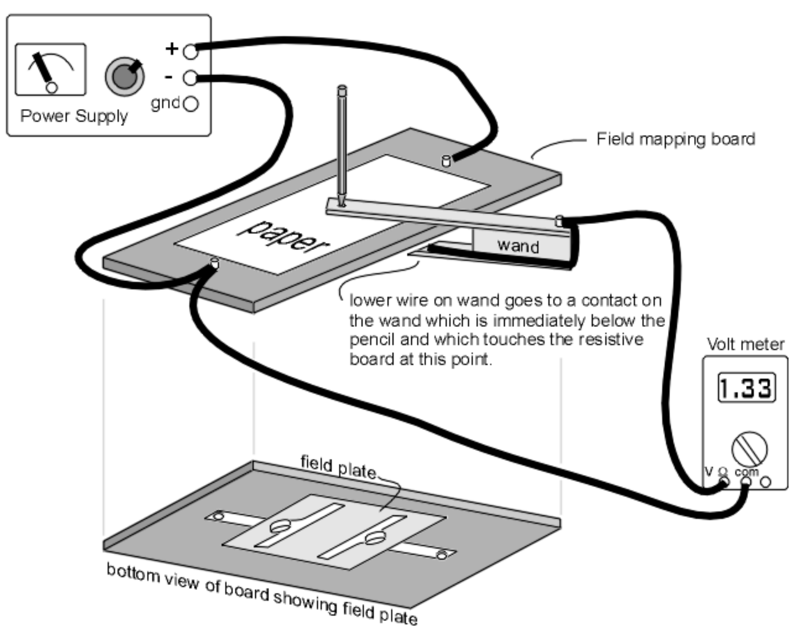


Figure 1.5: Diagram of electric field apparatus Setup



Simulation Procedure and Questions:
Using an simulation located at: http://www.falstad.com/emstatic/index.html one can explore how electric field lines add for multiple point and line charges and how the equipotental lines change for different charge distributions.

The default when first arriving to the website shows a single positive stationary charge and the associated equipotential lines as shown in Figure 1.
The arrows indicate the electric field around the charge, which is yellow (+). Notice that the arrows indicate the direction of the electric field at each point and the strength of the field is indicated by the change in color as the vectors move from the charge. The grey circles around the yellow charge are the equipotentials. Using your mouse, unclick the checked box "Draw Equipotentials". Notice that the circles disappear just showing just the electric field vectors. Now turn on the equipotentials again. You may increase or decrease the arrow resolution and equipotentials curves by moving the sliders on the lower LHS side of the simulation. Use this if more detail for the equipotential or electric field is required.

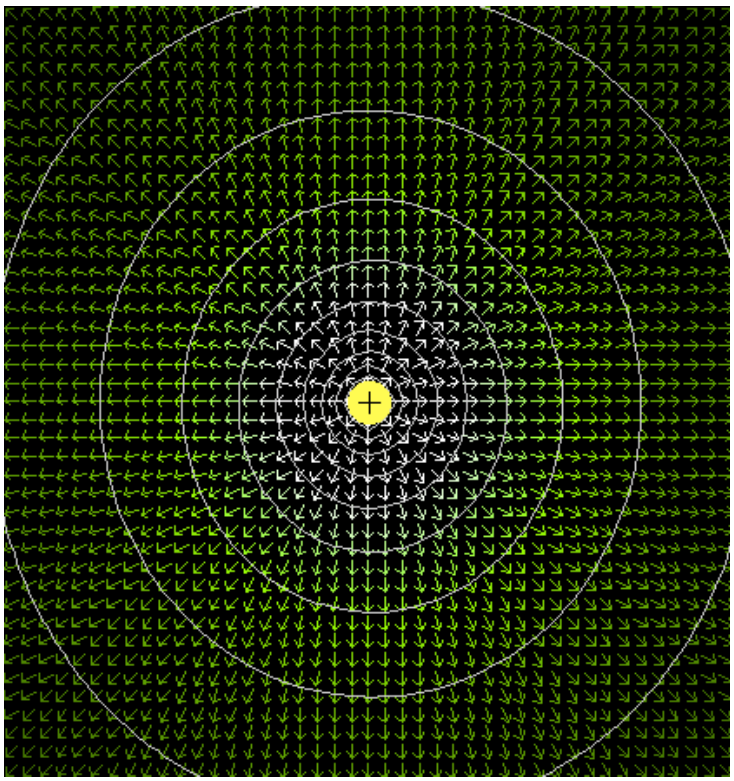


Figure 1: Screen

1. What is true about the electric field arrows and the circular equipotentials in this image? Hint: How do the electric field vectors intersect the equipotentials? Please explain why you believe this is seen.

Now, from the drop down **Setup menu** choose, **Setup: Dipole charge**. This changes the charge distribution from a single positive, yellow, charge to two charges of opposite sign but equal magnitude. This configuration is equivalent to the 'Circular Terminals' configuration of Page 3 of the Electric Field Mapping Laboratory.

Look at the electric field (you may again want to click off the equipotentials).

2. What is true about the electric field arrows close to the actual charges? How do these arrows compare with the single charge?

3. How are the arrow directions different around the negative charge than the positive one? Since the test charge is defined to be positive, can you make sense of the change in the arrow direction?

Now, turn back on the equipotentials.

4. Looking back at your answer to question #1, do you see the same relationship between the electric field arrows and the equipotentials? Is this expected? Explain.
5. What has changed about the shape of the equipotentials with the addition of a negative charge close to the positive charge? Explain why this occurs.
6. Now, move the negative charge around the black screen, does anything change in the field lines or equipotentials, describe fully. You may include screen shots as an aid to your explanation. Explain what stays the same and why.
7. How do you think the electric field will change if the additional charge were positive rather than negative? Explain.
8. How would the equipotentials change, would an equipotential line exist between the two charges? (Make prediction before continuing.)

Now, check your answer, from the drop down **Setup** menu, choose, **Setup: Double Charge**.

9. How did your answer in #7 compare with what you see from the simulation? Did your prediction agree with your answer? Explain why or why not.

Now, let's look at what happens when a line of charge is constructed. To do this, create a charge configuration equivalent to the 'Point and Plane' configuration on Page 3 of the Electric Field Mapping Laboratory. You may choose the point to be the positive charge and the plane to be made up of negative charges. To accomplish this configuration you simply need to go back to the default **single charge** using the **Setup Dropdown menu**. And then, using the **mouse dropdown menu** choose **add – draggable charge**. Now you can add negative charges in a line, note the simulation will not let you put the charges right no top of one another. Make a line of negative charges.

1. Are the electric field lines in this configuration similar to the single charge configuration? Explain.
2. Are the electric field lines in this configuration similar to the dipole charge configuration? Compare and contrast.

Finally, from the drop down **Setup** menu, choose, **Setup: Conducting Planes**. Each plane is an opposite charge as the point charges, yellow and blue. This configuration is similar to the Parallel Plate configuration on Page 3 of the Electric Field Mapping Laboratory. You can think of a plane as a group of point charges lined up side by side (similar to Point/Plane above), with no space between them. Each point will have its own field, but cancellation of the electric field in some directions will take place for adjacent charges.

3. Looking at the electric field shown in the center of the conducting plates, and think back to the dipole electric field. Think how one could construct a line by lining up single charges. How can the field seen near the center of the plane be predicted from a line of single point charges? It is helpful to imagine a row of very close positive charges as the continuous plate charge. (It may easier to answer this with a sketch.)
4. What would happen at the end of the plane using a line of single charges since the endpoint charge would only have adjacent charges to one side? Describe what the electric field looks like at the ends of the planes? How is this different from between the charged planes?

Experimental Procedure Equipment:

1. Two of the plate configurations in figure 1.4 have not been created using the simulation. These plates are the Faraday Pail and the Insulator/Conductor. One of these two plates you will be required to conduct your experiment. You will be assigned which plate to choose for your experiment.
2. Before assembling your apparatus, thinking about what you have seen in the simulation – as a group sketch out the predicted shape of electric field lines and equipotential lines for the plate configuration assigned in step 1.
3. Choose a plate from the selection provided. Note that the field plates are graphite-impregnated boards of an appropriate conductivity that have various silver painted electrode patterns printed on them as shown in Figure 1.4. The plate to be "mapped" is affixed to the bottom of the field mapping board as shown in Figures 1.5 and Figure 2 below.

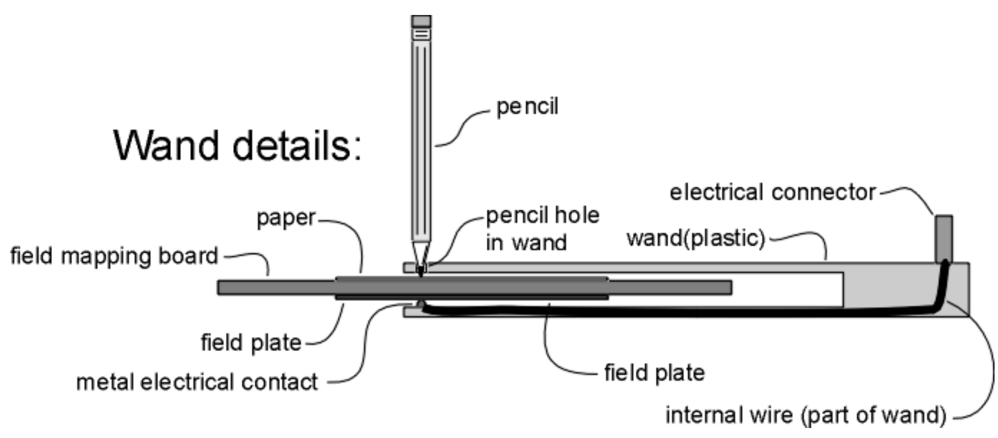


Figure 2: Side image of experimental setup

4. Now, press down on the apparatus and attached white paper under the springs (for extra securely apply a piece of tape) on top of the apparatus. Make sure to use the stencil to draw the electrode shape on the white paper before

starting. It is also a good idea to probe the all electrode areas of the plate and indicate the potential or voltage found using the U-shaped probe or "wand", see figure 1.6.

5. The stencils in the lab contain all the electrode shapes on them and conveniently fit over locating pins on the top of the field mapping board to allow one to quickly and accurately draw any of the electrode shapes on the paper. Each template has several electrode shapes on it, so a student has to pick out the shape that matches the electrode shapes of the field plate currently affixed to the board. When properly positioned on the pins, the template shape of interest should be immediately above the actual electrode on the other side of the board. Turn the board over and check for this before tracing out the electrode shape.
6. Now that the apparatus is setup, turn on the power supply and use the wand to probe for the same voltage. The normal procedure after setting up the equipment as shown is to first map out the middle equipotential, i.e. a potential or voltage equal to half the power supply voltage. For example, if the power supply is set at 4 volts, one moves the wand around and searches for a point of 2 volt potential and then with a pencil (or ball point pen) marks a dot at that point through a special pencil hole in the top portion of the wand. The wand is made so that the pencil hole is located immediately above the probing contact that touches the field plate affixed to the underneath of the field mapping board.
7. Continue in this manner until you have at least 5 equipotential surfaces (i.e. 5 different voltages mapped out in dots) on the page that are equally distributed around the charges. Make sure to map the area on both sides of charges and fill the page. Map out the number of equipotential surfaces to adequately fill the page.
8. After making the equipotential maps, students should draw the electric field lines. Figure 3 shows an example of mappings with both equipotential and electric field lines. Try to draw the electric field lines so they are reasonably uniformly spaced in any region of the mapping. At the same time regions of higher electric fields will have tighter spacing of these electric field lines. For ideal electrodes, the equipotential lines

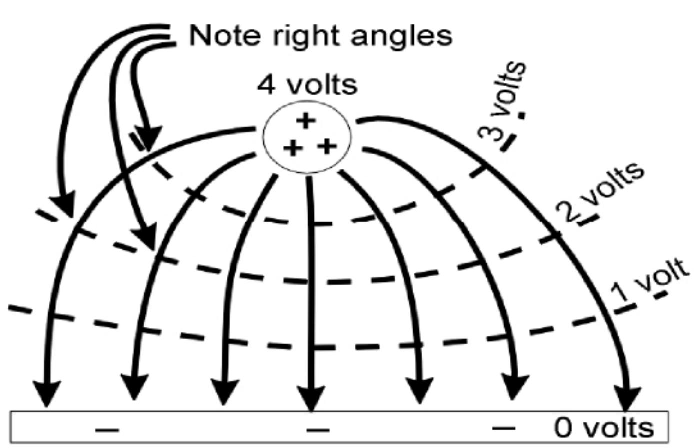


Figure 3: Example E-field lines from Equipotential surfaces

should run parallel to the edges (or surfaces) of the electrodes in the regions very near to the edges. Also in these regions, the electric field lines will run into the electrodes at a right angle to the edges. The printed electrodes in the experiment are not quite ideal (not infinite conductivity) and so you should expect some deviation from the parallel and perpendicular conditions next to the electrodes. You should however always be able to construct electric field lines that are everywhere perpendicular to the equipotential lines.

9. Write an experimental summary. Be sure to include comments on the simulation data vs. the experimentally gathered data.

If you are doing this laboratory as a Formal Lab report please follow steps below to compare you plate to results found in the Simulation. You may do this portion at home.

Return to the simulation and create the plate your examined in class following steps in (a) or (b) below.

Please note:

a. The simulation doesn't have a ready-made Faraday pail, so you must use charges close together to create the bottom and sides of the pail and the opposite charge above the pail. It does not matter which is set to positive, only that the pail be one charge and the single charge the opposite polarity.
b. For the insulator and conductor, one must choose the dipole setup and then add dielectric as the insulator and the conductor can been chosen as positive but must be given approximately half the brightness (brightness indicates the amount of charge in the simulation) as the top charge. (Here it is noted that the dipole configuration in the simulation makes the upper charge positive).

10. Take a snip (Windows) or grab (Mac) of the image and include it in your report. Compare the data acquired in class with the simulation results.