

## Electric Fields and Potentials

**Purpose of the lab:** The students will learn to map electric fields and potentials and to identify the fields for the dipole, parallel plate, and concentric cylinder (or sphere).

**Introduction:** You probably have some experience walking up hills and down hills. It's harder to run uphill because going uphill requires you to increase your gravitational potential energy. Going downhill is easier because the released gravitational potential energy assists you. If we consider the potential energy of a standard mass (say, a 1 kg ball), each point on the hill would be associated with a particular amount of gravitational potential energy. We could find sets of points on the hill where the ball has the same potential energy as it has at the other points in the set. If we connect these points, we'll get an "equipotential line." There are many equipotential lines, each representing a different potential energy. If we walked on the hill, following one of these equipotential lines, our potential energy would always remain the same. We would be walking neither uphill or downhill, but around the hill.

If walking on an equipotential is walking around the hill, following a field line, or "line of force," is like walking uphill or downhill. Field lines point in the direction that maximizes energy change. A ball naturally rolls downhill in the same direction as the gravitational field.

In general, field lines and equipotentials describe the space surrounding a mass or a charge or a magnetic pole. Coulomb's Law describes the force between two electric charges, just as Newton's Law of Gravity describes the gravitational force between two masses. Both equations are vector equations and both have the same form. Thus, your experiences of the force and energy changes when walking up and down hills is very similar to what happens when a small electric charge is moving in the "electric field" produced by larger charges.

The great physicist Michael Faraday visualized electric fields and potentials over 100 years ago. Many early books on electrical engineering are full of talk about the "density of lines." Field lines and equipotentials are a useful way to think about what electric force will be exerted on a charged particle that is in the vicinity of other charges. Closely spaced field lines are associated with large forces. Closely spaced equipotential lines are associated with rapid energy changes. You know that two magnets will jump together if they are brought near each other. Each magnet has a force exerted on it. The force on one magnet comes from the field surrounding the other magnet. While charges are not the same things as magnetic poles, their fields behave similarly.

In this lab, you will map some equipotential lines and use them to construct electric field maps for three configurations of charges: the dipole, the parallel plates, and the concentric cylinder. A dipole consists of one positive charge and one negative charge. The dipole pattern may be familiar to you, from your experiences with magnets. Parallel plates are used to create uniform electric fields, and to form a capacitor. Capacitors store charge and energy. The "coaxial" cable that brings your cable TV signals to you is a concentric cylinder.

Fields and equipotentials are related to each other in specific ways. The rules for constructing field lines are on the next page.

**The rules for field and equipotential lines:**

- Field lines start and end on conductors.
- Field lines never cross other field lines.
- Conductors are equipotential surfaces.
- Equipotential lines surround conductors.
- Equipotential lines never cross other equipotential lines.
- Field lines intersect equipotential lines and conducting surfaces at right angles.

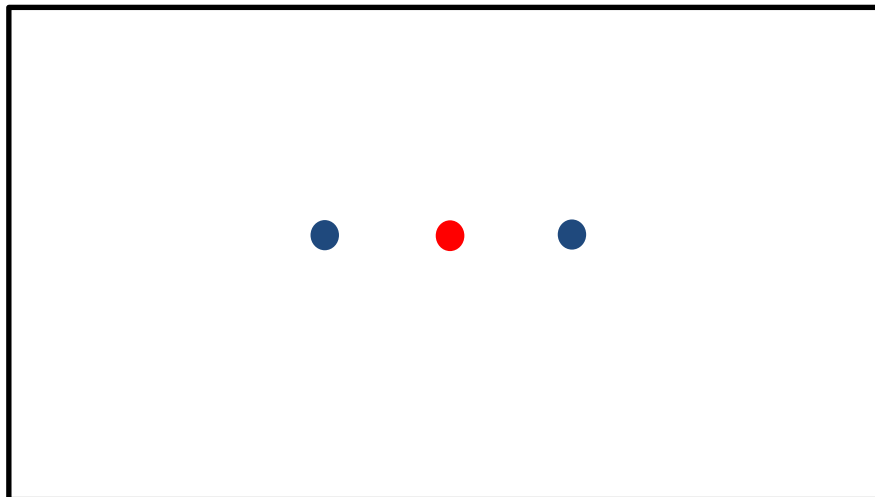
**Experiment 1: Virtual Lab (NO MORE THAN 10 MINUTES!)**

*Please use most of your lab time for working with your apparatus! These activities are fun, but you can play with them as much as you like outside of class.*

- Please go to <http://www.cco.caltech.edu/~phys1/java/phys1/EField/EField.html> Click in the black area to get started. You can adjust the strength and sign of the electric charges with the slide control.
- Alternatively, try <http://www.falstad.com/emstatic/> You can choose charge configurations, and whether to display electric field arrows or lines.

**What to do and what to notice:**

- Examine the electric field lines and equipotentials from a single electric charge. The field lines should radiate away from the charge, and the equipotentials should be concentric circles. Notice that the electric fields and equipotentials are perpendicular.
- Add a second charge. Notice that their fields add together. If the two charges are far apart, you can see that the single-charge pattern is still there in the area close to each individual charge.
- Set up the following charge configuration. Sketch the field lines. Using a different color, sketch the equipotential lines. The middle dot has a charge of  $+4$ , and the end charges are  $-2$ . Notice how the field and equipotential lines obey the rules stated above. Turn in this page with your data sheets.



## Experiment 2: Map electric fields and equipotentials for three electrode configurations

Your apparatus consists of a special sheet of electrically conducting paper. A pair of conducting electrodes has been painted on this sheet, using silver (real Ag) paint. You'll attach a wire to each of the electrodes so that one of them is charged to some positive voltage, and the other is at ground (0 Volts). This sets up an electric field in the paper, which you will measure with a digital multimeter (DMM).

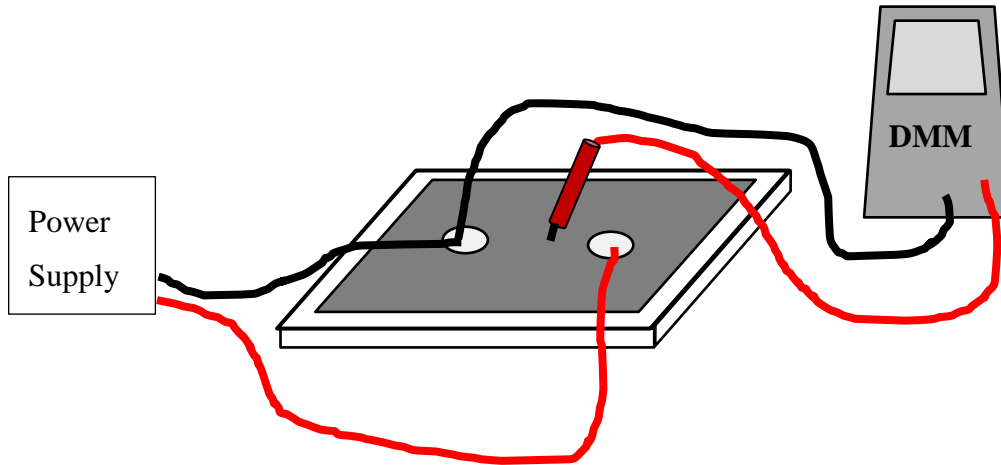


Fig. 1: Apparatus setup, showing how to connect the power supply and DMM to the conducting sheet.

### Apparatus Setup:

1. Take the conducting sheet with two point electrodes (two dots) and attach it to the cork board using plastic push pins in the corners.
2. Use metal push pins to attach a wire from the power supply to each of the two electrodes. You need a good solid contact between the silver electrode and the wires. Make sure that your connections are firm. Don't use old holes in the electrodes. Make new holes.
3. The DMM (Digital Multimeter) should be set to measure DCV (DC Volts, or Direct Current Volts). The test probes should be attached to the two right-most plugs in the DMM. One of these is labeled "COM", and the other is labeled "V $\Omega$ mA" or something similar.
4. Attach the DMM "COM" plug to one of the electrodes on your board. Let the other probe hang free for now.
5. Plug in the power supply and turn on the DMM. Touch the free probe to the other electrode. You should read 0V if you touch both DMM wires to the same electrode, and approximately +12V or -12V if you touch them to different electrodes.

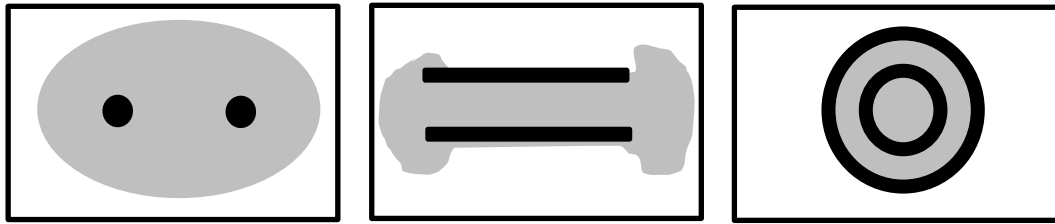


Fig. 2: The three electrode configurations. From left to right, they are the dipole, the parallel plates, and the cylindrical conductor. **Pay particular attention to the gray areas** when you're mapping the equipotentials.

### Taking measurements:

1. Touch the free DMM probe to various points on the paper. You should get different voltage readings at different spots on the paper. Touch the probe firmly to the paper. If the probe is pointed, use the flat side of the probe, not the sharp point. Don't stab the paper with the probe.
2. Note that the conducting paper has a coordinate grid on it. Draw the electrodes on a piece of ordinary graph paper, paying attention to their coordinates. Label the electrodes with their voltages. You will find it useful to use a coordinate system that has its origin at the center of the paper.
3. Now, select a convenient intermediate voltage (3V for example) between 0V and 12V. (If your voltages are negative, either switch the DMM leads or ignore the minus sign.) Find a number of points with this voltage, and mark their locations on your graph paper. "Connect the dots" to create an equipotential line for 3V, and mark it "3V".
4. Repeat this procedure for several different voltages. You will need at least half a dozen equipotential lines so that you can use them to construct the electric field pattern. Pay attention to the parts of the pattern highlighted in gray in Fig. 2.
5. Proceed to the analysis, below. **Do NOT take apart the apparatus** until you have completed your analysis by constructing the field lines for the pattern! You may need to re-measure some points. Finish measuring and analyzing one pattern before proceeding to the next.

### Analysis:

At this point, your graph paper should have several equipotential lines on it. Construct the field lines as follows:

1. Start at one of the conductors.
2. Field lines always enter and leave conductors at right angles. Draw a very short line coming out of a conductor at right angles to its surface. Use a different color than you used for the equipotentials.

3. Field lines always intersect equipotentials at right angles. Extend the line that you started, bending it gently so that it crosses the nearest equipotential line at right angles.
4. Continue drawing the field line, always crossing the nearest equipotential line at right angles.
5. If you need more equipotential lines, or need to check the ones you have, please do so. Your apparatus is still set up.

Please repeat the procedure and analysis for the other two patterns of electrodes. If time permits, you may check your patterns by using the Java applets. You can simulate extended electrodes by arranging several identical charges in rows or circles.

### **Clean-Up Checklist:**

- Please turn off the DMM.
- Disconnect the wires.
- Remove the electrode sheet from the board. Put the push pins back in the board.
- Return borrowed red pens.
- Please tidy up your table.

*Thank you!*

### **Just for Fun (outside of class):**

Electric fields in “real life” are 3-D, not 2-D. There are some excellent interactive animated Java applets at <http://www.falstad.com/vector2de/> and <http://www.falstad.com/vector3de/>, and links to more at <http://www.falstad.com/mathphysics.html>. In these simulations, you can see how small charged “test particles” move in the electric fields.

If you're in the mood for a game, try the PhET Project's Electric Field Hockey. It's a lot of fun! Level 3 isn't easy. <http://phet.colorado.edu/en/simulation/electric-hockey>

P31220 lab

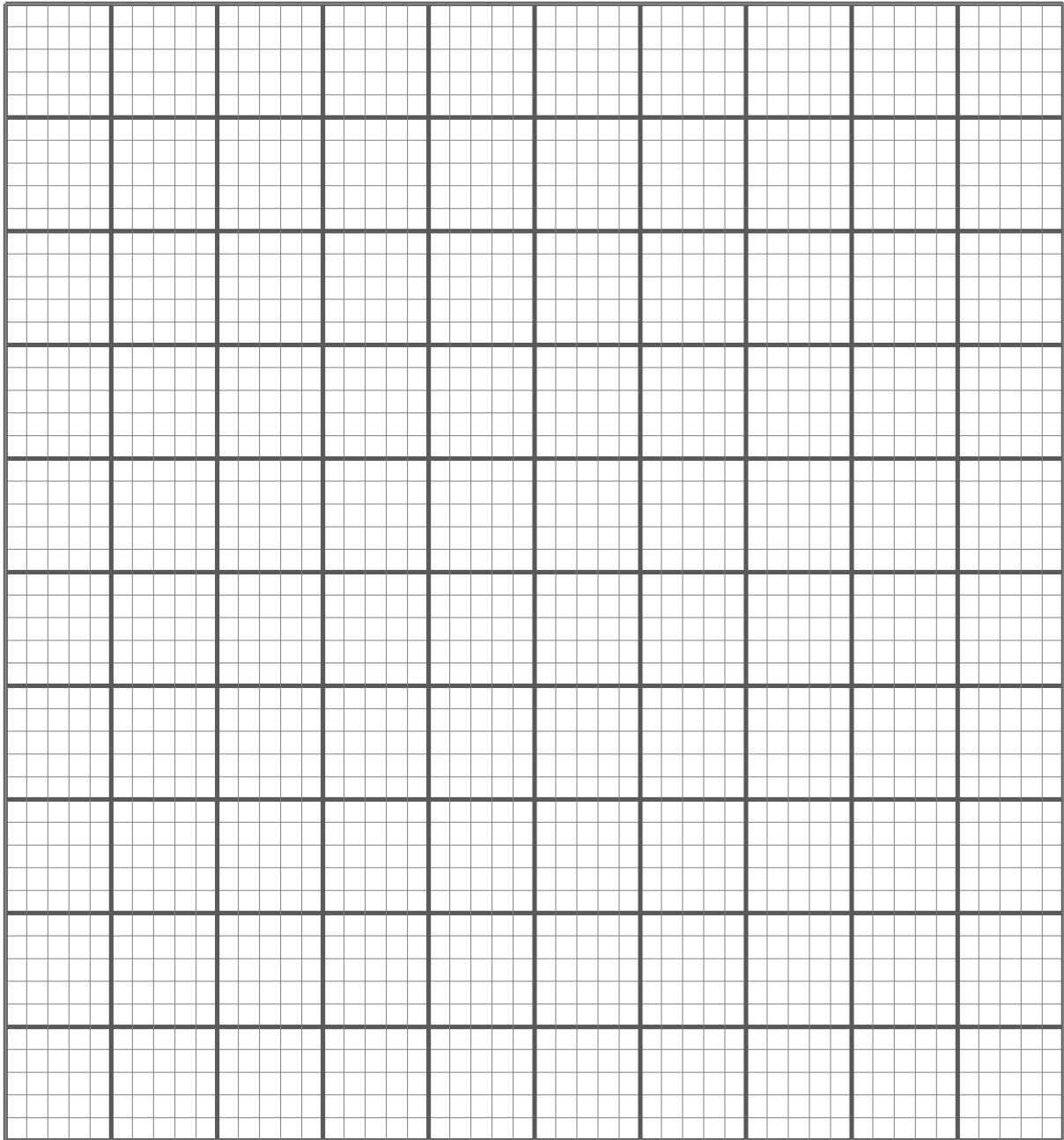
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### Data Sheets:

Please turn in your three drawings of the field lines and equipotentials, as well as the sketch on page 2 and the Analysis Questions. No data tables or error analysis are required.

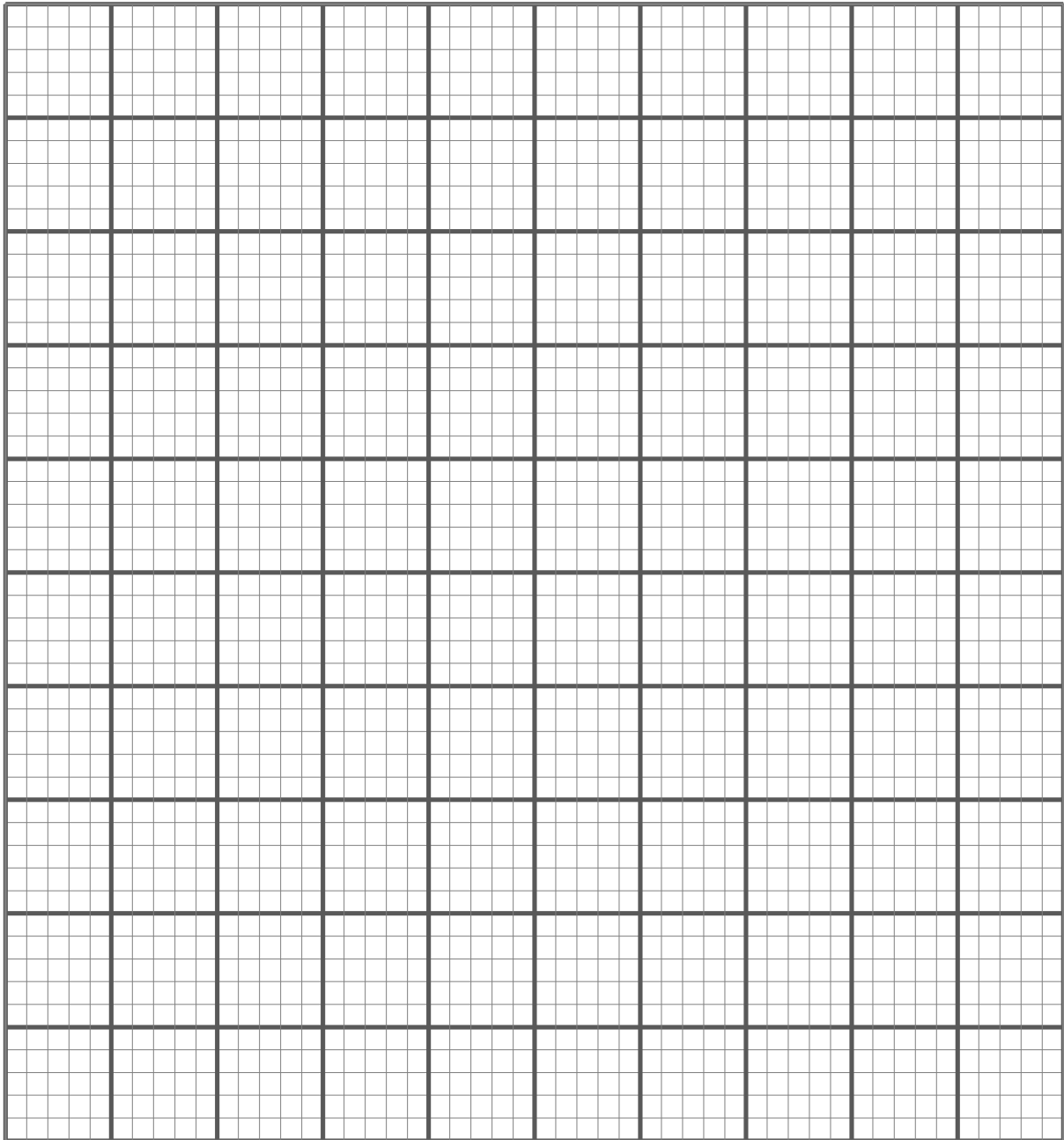


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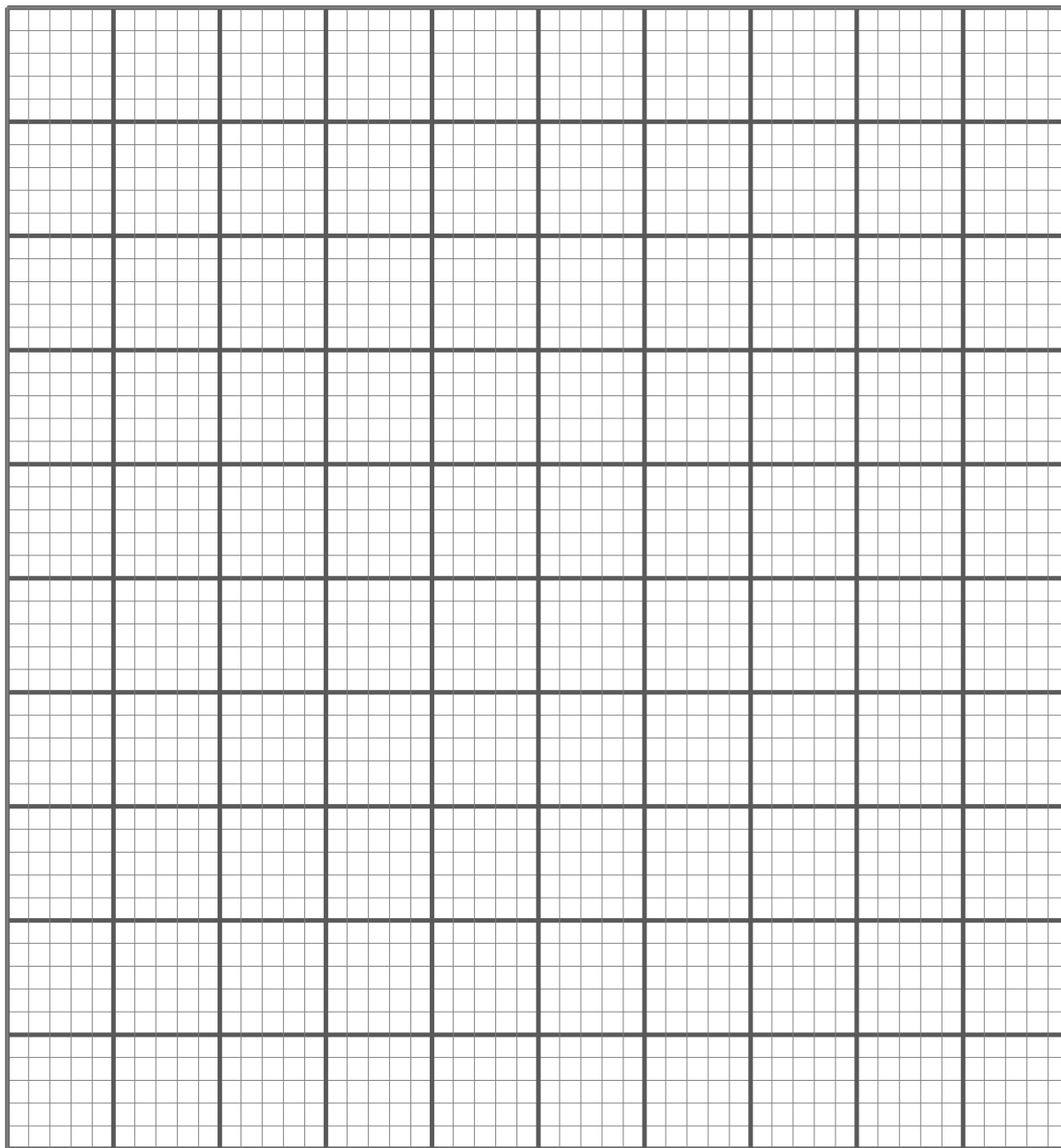


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**Analysis Questions:**

1. How well did your actual measured maps match those from your textbook or the online applets? Please give this some thought.
2. Which of the three electrode configurations would you choose if you wanted to create a uniform electric field?
3. The concentric circle electrodes can be thought of as the cross section of a coaxial cable. Coaxial cables have an inner conductor and an outer conducting shield, separated by an electrically insulating layer. Coaxial cables are commonly used to bring cable TV into your house. Can you think of a reason why coax cable is used for this purpose instead of plain wire?
4. What did you discover about the area inside the center of the concentric circle pattern?
5. What did you discover from playing with the online applets? Please give this some thought.
6. What are your final thoughts and impressions about this lab? If you did any of your own experiments, this is a good time to talk about them! Use the back or attach pages if you need more room.