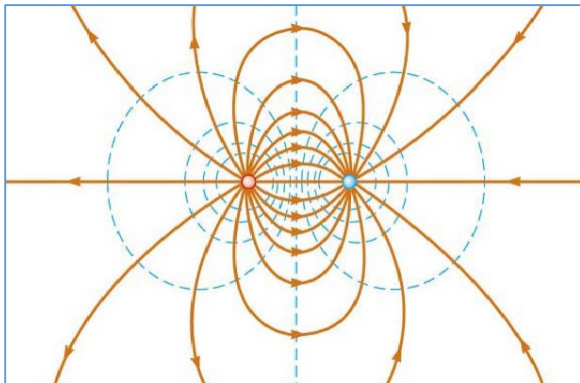


Electrostatic Fields & Mapping of Equipotential Lines

Equipment	Quan
Field Mapper Kit	1
Multimeters	2
Multimeter probe	1

Electric fields are everywhere. The field due to the electric charge of an atomic nucleus attracts electrons, creating the atom, but also atomic bonds (allowing solid matter to exist) and it also drives chemical reactions. And in hundreds of electrical devices, electric fields accelerate electrons. For example, the filaments of a fluorescent light bulb produce fields that send electrons bashing into gaseous mercury atoms, causing them to produce light.

The figure below shows lines of electric flux (solid lines) connecting a positively (left) and a negatively (right) charged particle.



The force on a second positively charged particle in this field is parallel to the field line (and in the direction of the arrows) at the position of the particle. Since a force exists, then work is done if the particle moves along the line, and the particle moves toward lower electric potential. The dashed lines are electric equipotential lines. The particle gains energy as it passes to lines of lower potential, just as a

rock rolling down a hill gains kinetic energy as it moves toward lower gravitational potential.



Since the SI unit of electric potential is the *volt* ($1\text{ volt} = 1\text{ joule/coulomb}$), we can label the potential lines in *volts*. In this exercise, you'll measure the electric potential at many points in the vicinity of a pair of electrodes (one at a potential 15 V above the other) that are printed on a sheet of conducting paper. You'll then use MS Excel to plot a 3D graph displaying electric potential as a function of 2D position on the sheet. This will reveal the electric equipotential lines, from which you'll be able to construct the structure of the electric field lines.

Procedure

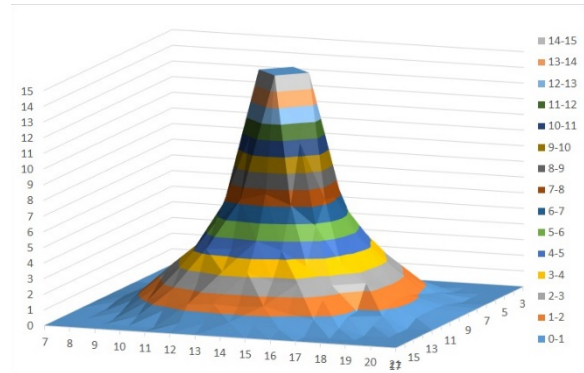
1. Find the conducting page with the circular outer electrode. Use pushpins at its corners to secure it to the center of the cork board.
2. There are two wires in your mapping set that can be used with pushpins to connect the two electrodes to the positive and negative DC plugs of the low voltage power supply. Connect the center electrode to the positive plug.
3. Connect the negative plug of the power supply to the COM socket of the multi-meter using a BB wire.
4. Plug a multi-meter probe (the wire with a pointy end) into the $V\Omega$ socket of the multi-meter.
5. Ask the instructor to check your setup before turning on the power supply.
6. Turn on the power supply. Set the DC voltage to 15.0 and the DC current knob to the halfway position.
7. Since we'll be measuring voltages from 0.0 to 15.0, set the multi-meter to the 20 volt DC setting.

8. To check that everything is working, measure the voltage of the center electrode, which should be 15.0 V. Also check the outer electrode, which should read 0.0 V, and any point in the region between the electrodes should read somewhere between 0.0 and 15.0 V.
9. Find the data sheet that's prepared for the circular electrode.
10. The conducting paper is labelled with coordinate systems corresponding to the numbers on the data sheets. Your instructor will tell you how many of the table cells need to be filled in for this electrode configuration.
11. Once all the required cells are filled in on the data sheet, transfer this data to the cells of an MS Excel spreadsheet. It should look something like the figure below, and should include the coordinate numbers from the conducting sheet (these cells I've changed to blue for clarity).

	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
17						0	0	0	0	0	0				
16				0	0	0.39	0.5	0.65	0.51	0.37		0	0		
15			0	0.36	0.8	1.32	1.43	1.35	1.5	1.12	0.83	0.38	0		
14		0	0.27	1.01	1.88	2.35	3.21	3.26	2.77	2.76	1.8	0.85	0.35	0	
13		0	0.68	1.64	3.1	4.28	4.4	5	4.47	3.55	2.47	0.9	0.71	0	
12	0	0.23	1	2.3	3.58	5.67	7.26	7.7	7.1	5.85	3.53	2.43	1.19	0.41	0
11	0	0.34	1.12	2.68	3.99	6.74	11	15	10.8	7.3	4.36	2.52	1.3	0.44	0
10	0	0.28	1.03	2.45	4.22	7.07	15	15	15	7.16	4.69	2.68	1.23	0.45	0
9	0	0.26	1.05	2.41	3.72	5.66	13.5	15	10.4	6.4	4.13	2.59	0.98	0.38	0
8	0	0.22	0.74	2.01	3.15	4.5	5.75	5.68	6.45	5.15	3.46	2.01	0.73	0.21	0
7		0	0.45	1.16	2.45	3.19	3.83	4.86	4.28	3.97	2.8	1.49	0.56	0	
6		0	0.27	0.83	1.42	2.11	2.63	2.97	3.09	2.8	1.48	0.95	0.24	0	
5			0	0.28	0.8	1.08	1.52	1.31	1.64	1	0.54	0.23	0		
4				0	0	0.33	0.53	0.62	0.54	0.42	0	0			
3						0	0	0	0	0					

12. When the data is ready in the spreadsheet, highlight the data (including the coordinate numbers) and click on the "insert" icon.
13. Choose a surface plot (first click , and then .
14. You can change parameters of the plot to improve the presentation of the data. Some suggestions are in a section at the end of this write-up.

15. Your plot should look something like the figure below.



16. Repeat the mapping procedure for any other electrode configurations that your instructor requires.

The colors on the plot represent ranges of electric potential (as indicated by the legend on the right-hand side). As a positively charged particle moves away from the center electrode, it moves toward regions of lower potential (think of the analogy of the rock rolling down the hill). Also, we know that electric field is the gradient of the electric potential:


$$\vec{E} = -\nabla V_e$$

This is visually illustrated in our plot. The steepness of the slope in the plot represents the gradient of the potential, and thus the strength of the electric field. The fact that the slope is highest near the center should make sense since you know that an electric field is strongest near a localized charge.

Drawing Electric Field Lines Based on the Equipotential Lines

Since we know that equipotential lines and electric field lines are perpendicular, you can make a diagram of the field using a diagram of the potential field.

17. This works best for the dipole plot.
18. Right click on the graph and choose "Change Chart Type."

19. Choose the  icon. This takes the surface quality away from the plot.
20. Make sure that the major unit for the vertical axis is set to "1" (instructions below).
21. Right click on the graph and choose "3D Rotation."
22. Change Y Rotation to 90° and set X Rotation such that the plot area is square with the window frame. Also, change the Perspective angle to 0.1°
23. You now have a plot of the potential lines, which you can print out and use to draw the electric field lines.
24. Remember that the electric field lines are always perpendicular to the lines of equipotential. This simple fact can guide you in the construction of the field lines.

Suggested Changes to Improve the Surface Plot's Appearance

1. The numbers on the coordinate axes are probably a little small. You can right click on the numbers of one of the axes and a box will appear around those axis numbers. In the "HOME" tab you can then change the font size value.
2. You can move the legend to the right side by right clicking on it, choosing "Format Legend," and choosing "Right."
3. You can change the number of potential levels with separate colors by right clicking on the vertical scale numbers, choose "Format Axis," and set Major Unit to "1."
4. Controls for rotating the graph in 3D space by be obtained by right clicking on the graph and choosing "3D Rotations."
5. There is a "Perspective" value in the 3D Rotations panel. It's often better to reduce the perspective to 0.1°. This is

especially helpful when you're printing out the potential plot in step 23.

Questions

1. For each plot, describe in words the location of the strongest electric field (the strongest field is where the slope of the potential surface plot is steepest).
2. Which plot has a region with a highly homogeneous electric field? In other words, where are the field strength and direction constant over a large area?
3. What familiar 3 dimensional electronic component has a homogenous field similar to the one between the two parallel line electrodes?
4. If the two parallel lines were half as far apart as they are, how would the slope of the potential surface (and thus the strength of the electric field) between them compare with the slope that you plotted?