THE ELECTROSTATIC FIELD

Introduction: In this lab we map out the electrostatic field ($\mathbf{E}$) around electrodes in a water bath. We do so by measuring the voltage drop between two closely separated pins placed in the water. Knowing the distance $d$ between the pins and their orientation, we can find the average electrostatic field between the pins. You may ignore errors for this lab. Text Reference: Wolfson 23.4-5, 24.1, 24.6, 25.2.

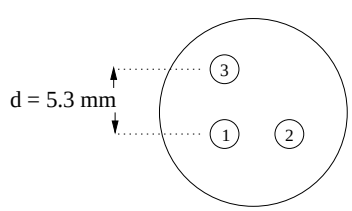
Theoretical Note: The absolute value of the average $x$ component of the electrostatic field ($\overline{E_x}$) between two points separated by a distance $|\Delta x|$, and between which the absolute value of the voltage drop is $|\Delta V|$, is given by

$$|\overline{E_x}| = |\Delta V|/|\Delta x|, \tag{1}$$

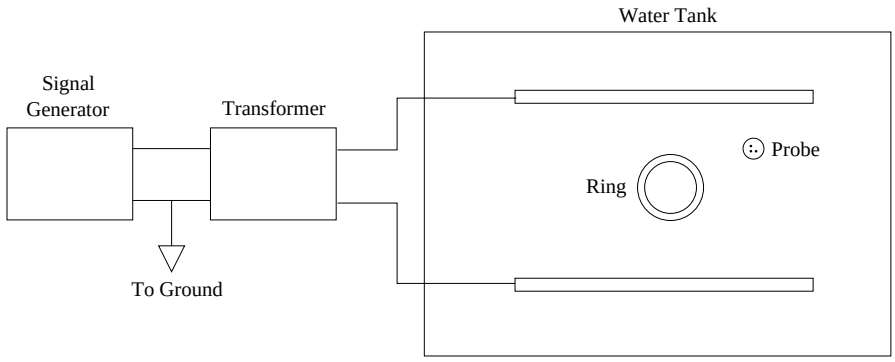
with similar equations for $y$ and $z$. The electrostatic field always points from high potential to low potential.

Procedure: You will use a three-point probe (see figure below) to determine the electrostatic field strength and direction at a number of locations near some charged and neutral conductors. Having the electrostatic field vectors, you will then draw the appropriate electric field lines for the given conductor configuration.

A sketch (not to scale) of the working end of the three-point probe is shown below. By using the oscilloscope in the "XY" mode, you will be able to measure simultaneously the voltage drops between pins 1 and 2 (the $x$ pins) and between pins 1 and 3 (the $y$ pins). The $x$ and $y$ directions are marked on the side of your three-point probe. The $x$ and $y$ components of the electrostatic field can then be calculated with equation (1). IMPORTANT: Once you have selected your $x$ and $y$ directions, you must maintain the orientation of the probe as you move it to different locations in the tank. The probe should reach the bottom of the tank and should not be tilted.




A sketch of the apparatus, with connections, is shown in the figure at the top of page 2. We use an AC source to generate the field in the water tank; a DC source would result in a build-up of charge near the electrodes. The function of the transformer is to allow the potential of both conductors in the water tank to be independent of ground. Pin 1 on the three-point probe is grounded; if either conducting bar were grounded, then the presence of the probe would drastically affect the electrostatic fields that we are trying to measure.

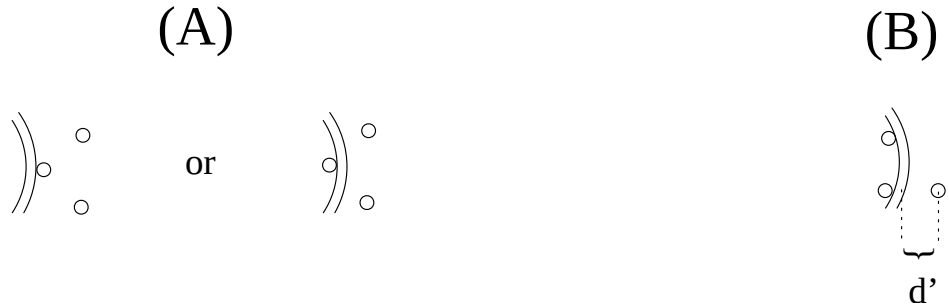



Before beginning the formal experiment, you must check the calibration of the three-point probe. Put the conducting bars at $D = 12$ cm apart; do not use the central ring during the calibration. Set the signal generator for a 200 Hz sine wave with maximum amplitude. Set the scope inputs on XY, with a scale of 1.0 V/div. Put the probe near the center of the tank. If you rotate the probe, you should see a rotating line on the scope. (Some groups may see a rotating ellipse; this is due to an $x$-$y$ phase difference in some of the probes and should not affect your measurements.) The angle of the line on the screen (measured from the $+x$ screen direction) corresponds to the angle between $\mathbf{E}$ and the $x$ pins of the probe, at the location of the probe (this is a choice – since we are using 200 Hz AC, $\mathbf{E}$ is reversing direction 400 times a second). The maximum voltage drop between the $x$ pins ($V_{pin,x}$) and between the $y$ pins ($V_{pin,y}$) can be read directly from the screen, for any selected angle of the probe (make sure your line, or ellipse, is centered, or else measure from end-to-end and divide by two). The maximum values of $\overline{E_x}$ and $\overline{E_y}$ can then be calculated with equation (1) and the distance $d$ between the pins.

To check the probe's calibration, first measure the RMS voltage between the bars with the DMM. Calculate the amplitude of the AC voltage, and then the maximum average electrostatic field between the bars ($\overline{E}_{DMM}$) using equation (1); we will compare $\overline{E}_{DMM}$ with the value of $\overline{E}$ that we measure with the three-point probe. Now use the three-point probe to measure $V_{pin,x}$ and $V_{pin,y}$ for probe orientation angles of 0°, 45°, 90°, 135°, and 180°. Keep the probe in the center of the tank while doing so. Calculate $\overline{E_x}$, $\overline{E_y}$, and $\overline{E}$ for each angle. Do this by hand. Is the value of $\overline{E}$ independent of the orientation of the probe? How does the value of $\overline{E}$ compare with $\overline{E}_{DMM}$? Write your answers to these questions in a precise scientific manner; agreement to better than 10% is reasonable.

For the formal experiment, put the conducting ring in the center of the tank. You will have placed a neutral conducting ring between the oppositely-charged conducting bars; your task is to draw a reasonably accurate representation of the electric field lines which result. Begin by checking that $\overline{E} = 0$ inside the ring. Now confirm that the direction of $\mathbf{E}$ at the outer ring surface is normal to the ring (use the pin orientation shown in part (A) of the figure on page 3). Although you can't check it, the $\mathbf{E}$ at the conducting bars

must also be normal to the bars. Next measure the maximum value of $\overline{E}$ at the outer ring surface (you actually measure $V_{pin}$ and calculate $\overline{E}$). Do this in one quadrant at angles of 0°, 22.5°, 45°, 67.5°, and 90° on the ring (0° is parallel to the bars). Draw lines on the paper to mark these angles. Use the pin orientation shown in part (B). The effective pin-to-pin distance is shortened by the presence of the metal ring between the pins; use $d' = 4.3$ mm for your calculation in this part. Again, do all of this by hand.




Some of your electric field lines will go from bar to ring; however, there will also be electric field lines that go directly from bar to bar. We would like to determine the approximate location, in each quadrant, at which electric field lines from the bars go directly across rather than going to the ring. Work along a line parallel to one of the bars and about 2 to 3 cm from the bar. Move the probe along this line, maintaining a constant orientation of the probe; note the changes in the angle of **E** at the probe's location as you do so. Record the approximate location in each quadrant at which the direction of **E** ceases to bend towards the ring, and begins to point directly towards the other bar. Take the average of these four values as the location at which the electric field lines will begin to go directly across from bar to bar. Report this location in your conclusions.

At this point you should have a qualitative mental picture of the final electric field lines. Now use the probe (you must maintain a constant orientation) to measure the maximum values of $V_{pin,x}$ and $V_{pin,y}$ at about half of the accessible grid points in one quadrant. Enter these in GA and calculate columns of the maximum values of $\overline{E_x}$, $\overline{E_y}$, and $\overline{E}$ as well as $\theta = tan^{-1}(\overline{E_y}/\overline{E_x})$ for each measured grid point. Draw these **E** vectors on your plotting paper (to scale, enter your scale factor on your plot). Also draw the **E** vectors that you have determined at the surface of the ring.

Finally, in a different quadrant of your plotting paper, draw your final qualitative electric field lines. You will be graded on the quality of your drawing. Your electric field lines should be in qualitative agreement with your **E** vectors. Your lines should be perpendicular to all conducting surfaces, and the density of your lines at any particular location should be proportional to the electrostatic field strength at that location.

Prelab Quiz PHY132

The Electrostatic Field

Name

Section Time and Day

1. List the properties of electric field lines (see, for example, Wolfson 24.1).

2. Qualitatively draw the electric field lines for a pair of finite conducting plates with equal and opposite charges (see, for example, Wolfson 24.6).

3. What is the magnitude and direction of the electrostatic field at a point where the $x$ component of the field is 22.3 N/C (or V/m) and the $y$ component of the field is 11.3 N/C (or V/m)?

4. For the electrostatic field given in (3), what is the absolute value of the voltage drop between two points separated by: (a) 1.5 mm in the $x$ direction? (b) 1.5 mm in the $y$ direction?