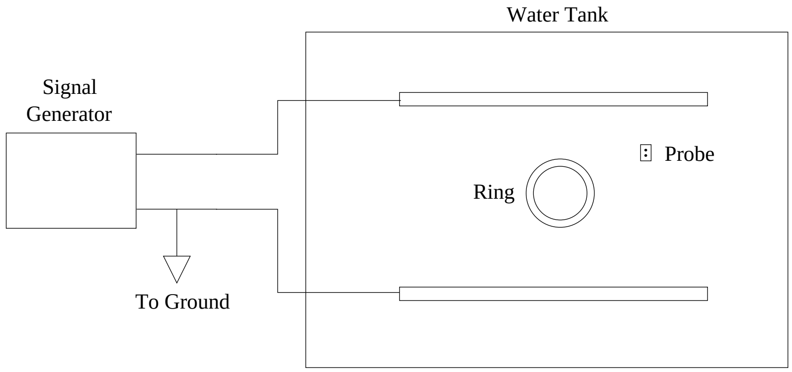
ELECTRIC POTENTIAL AND ELECTRIC FIELD

Introduction: In this lab we map out the electrostatic potential (V) around electrodes in a water bath. We do so by measuring the voltage drop between one fixed location and a large number of varying locations in the water. From these measurements we can also determine the associated electrostatic field. Text Reference: Y&F 23.2,4-5.

Theoretical Note: At this point the summer, you do not yet have a precise definition of the electrostatic potential V (usually just called the electric potential). Nevertheless, in this lab, you will study the relationship between V and the electrostatic field $\vec{E}$. The electric field always points from high potential to low potential, and in this lab you will learn that, roughly speaking, the electrostatic field strength E at any point of interest can be easily calculated from a map of the electric potential by taking the potential difference between two closely-spaced points on either side of the point of interest and dividing by the distance between those two closely-spaced points. This description of the relationship between $\vec{E}$ and V is quite rough; but after completing this lab, you should be able to explain exactly how to calculate the electric field strength and direction from any detailed potential map.

Procedure: You will use a set of charged conductors in a water tank to create an electric field in the water. You will use a digital multimeter (DMM) to measure the RMS voltage drop between a selected fixed location and a number of varying locations in the tank. You will then draw the appropriate equipotential lines (lines of constant potential).

A sketch of the apparatus, with connections, is shown in the figure below. 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 figure shows two parallel metal bars with a metal ring in between; your first set-up will be similar to this one but without the ring.



Part (1a): Create the set-up shown in the figure, but don't use the metal ring; there should be a piece of graph paper under the tank from which you can read coordinates. Use the signal generator (f = 200 Hz, amplitude maximum) to generate an AC signal between the bars. Pick one of the two bars as the fixed location for the black lead from your digital multimeter (DMM); this location becomes the SELECTED location at which the potential is zero. Use the red DMM lead to measure the RMS voltage at various locations within the tank. Begin by recording the RMS voltage at the other bar (note that this voltage is independent of the placement of the red lead on the bar). Record your data on a separate piece of graph paper. Your objective is to trace six equipotential lines in one half of the tank; take advantage of the symmetry of the set-up to deduce the continuations of those lines in the other half. Each line will have a distinct voltage; you must find enough locations having that voltage to trace the equipotential line throughout your selected half. Indicate your actual data points with small circles, and label each line with its RMS voltage. Ignore errors for this part.

Now select a location between two contour lines, away from the tank center but halfway between the ends of the bars. Determine the approximate RMS electrostatic field at this location (the difference in potential divided by the distance between the two lines), based on your data for equipotential lines (the field direction will be determined by your selected location of zero potential – the actual field is reversing direction 400 times per second). Then measure the field at the same location, using a two-point probe; this is simply a set of DMM leads clamped together at a fixed small separation distance. The two points of the probe should be on either side of your selected point of interest. To determine the direction of $\vec{E}$, you will have to rotate the probe until the DMM reads the largest possible RMS voltage. The RMS electric field strength is this largest RMS voltage divided by the distance between the pins. Compare the two values in your discussion. Though we are ignoring errors for this part, you still must write your discussion in a precise scientific manner; agreement to better than 5% is reasonable. How does the direction of $\vec{E}$ relate to the direction of the nearby equipotential lines? To remind ourselves that we are looking at an AC signal, draw a graph of the x component (let x be the direction from one bar to the other) of the electric field (at your selected location) versus time. Remember that you are measuring RMS voltages.

Part (1b): We now wish to investigate the effect of adding a neutral conducting ring halfway between the two bars. Three rings are provided; use the middle-size ring. Your objective is again to trace the equipotential lines in the tank; this time trace eight lines in one half of the tank. Be sure to measure the RMS voltage at the center of the tank and at several other locations within the ring. What is the electric field strength inside the ring? Check the electric field outside the ring at two or three interesting points. In this case, how does the direction of $\vec{E}$ at various locations relate to the direction of the nearby equipotential lines? On your tracing of the equipotential lines for this case, make a qualitative drawing of the electric field lines; please use a different color ink or pencil so that the two sets of lines are easily distinguishable.

Part (2): Create a set of dipole conductors by using pennies and clamping them to the bottom of the tank with the long conducting braces provided with your equipment. Each connection between conducting brace and penny must be tight. Put the centers of the pennies 12 cm apart, with the tank center halfway between the pennies. Trace about six equipotential lines in one half of the tank. WARNING: Because of the presence of the glass boundary, these equipotential lines will not look exactly like those of a dipole. Check the electric field at a couple of locations.

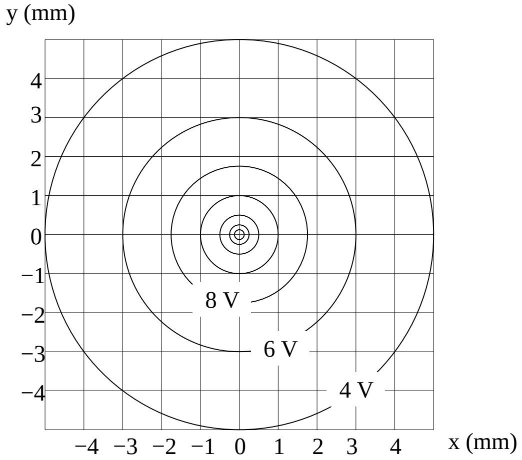
Part (3): Remove the pennies and the braces. Use the largest ring and the smallest ring to set up a pair of oppositely-charged coaxial rings; the leads from the signal generator should be connected directly to the rings using alligator clips. Select the inner ring as your location of zero potential and measure the RMS voltage at five different radii (measured from the common axis – all five radii should be larger than the radius of the inner ring and smaller than the radius of the outer ring); for each radius r, measure V_{RMS} at angles of both 0 and 180°. Enter these measurements in GA. Create a calculated column of $\ln(r)$, and plot V_{RMS} vs. $\ln(r)$. Your result should be linear; determine the slope and intercept, with errors, and state your result for $V_{RMS}(r)$ in your conclusions.

If you know how to apply Gauss' Law for cylindrical symmetry, you may use the results from your graph to obtain an estimate for the RMS charge on the inner cylinder; you will need to measure the length of the cylinder. NOTE: To make this estimate, you must assume that the two cylinders are infinitely long. This assumption is not absurd because the space between the rings is filled with water, which is a reasonably good conductor, and because we are using AC. For either direction of the alternating current, charges quickly gather on the upper and lower surfaces of the water until the field in the water is purely radial, and radially symmetric, as it would be for infinitely long conductors.

Prelab Quiz PHY132
The Electrostatic Potential

Name
Section Time and Day

1. From the potential map shown below estimate the electrostatic field **E** at the point $(x,y) = (2\text{ mm}, 1\text{ mm})$. Draw the **E** vector on the map, and give E_x, E_y, and E. The outer three equipotentials are labeled; the potential continues to increase by 2 V per equipotential as the radius of the equipotentials decreases.



2. List the properties of electric field lines (see, for example, Y&F 21.6).

3. Qualitatively draw the electric field lines for a pair of finite conducting plates with equal and opposite charges (see, for example, Y&F 22.4).