Demonstrating a Method to Create a Low-cost Electrophoresis Rig Solution

Srikar Baru, Vikram Choudhury, Pooja Thaker, Nathan Martin, and Danyal Ahmad

***Abstract*—We observed and analyzed the potential and electric field in a saltwater solution with conducting wires that could be used for a low-cost electrophoresis rig. Specifically, we inspected the formation of equipotential regions in the saltwater solution because they are especially important for the functions of an electrophoresis rig in organizing particles by charge and mass. To do this, we measured the potential difference (compared to a common point) at various set points in the saltwater solution, for various voltages. We expected to have equipotential regions that are able to be represented with elliptic curves and to have a non-constant electric field. We found that solution is a good low-cost substitute for electrophoresis rig solution as it creates equipotential regions suitable for the electrophoresis rig's applications.**

***Index Terms*—electric potential, equipotential lines, electric field visualizations, saline conductive medium, electrostatics, electric field mapping, data visualization in electrostatics, gel electrophoresis, electric field dynamics**

I. Introduction

DIFFERENT PARTICLES will settle at different regions in a solution based on their size and charge (negative charged particles will rest at higher potential regions and positive charged particles will rest at lower potential regions). An electrophoresis rig separates particles based on size and charge by having equipotential regions that different particles will settle at. A solution that is very conductive is needed to create a good separation between different particles. Salt (NaCl) dissociates into its ions (Na^+ and Cl^-) in water, allowing for a high conductivity as the ions are free to carry charge in the aqueous solution. This allows for a higher current density by the equation $\vec{J} = \sigma\vec{E}$, where $\vec{J}$ is current density, σ is conductivity of the material (very high for saltwater), and $\vec{E}$ is the electric field, which allows for clearer voltage differences across the rig as a higher current means a higher voltage by Ohm's law.

Placing a fixed positive charge (The positive terminal of a power supply) and a fixed negative charge(The ground terminal of a power supply) into this saltwater will create an electric field. This field will not be constant(it will be maximized close to each charge and minimized at the point exactly between them) and will never be zero between the two charges (both charges' electric fields are never in opposition in the region between them). Since $V = \int \vec{E} \cdot d\vec{s}$, there will be a potential gradient (since $\vec{E}$ is never 0) and this potential gradient will change inconsistently (as $\vec{E}$ is not constant in the solution).

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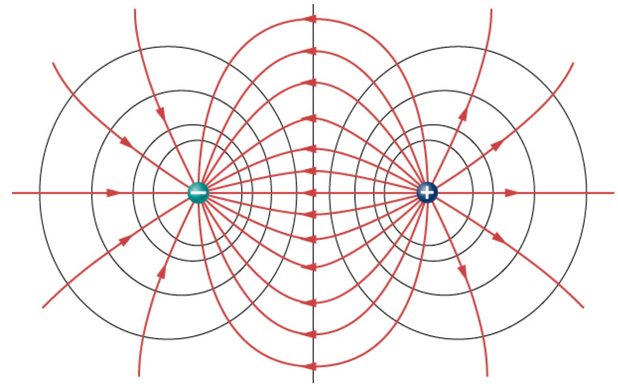

Fig. 1. Electric field (red) and equipotential (black) lines for a dipole configuration with positive and negative charges spaced by a short distance. From [1].

Certain points in this gradient will have the same potential, these points are considered to have equipotential. A region of these points is called an equipotential region and will run perpendicular to the net electric field. In this case, they should follow the pattern shown in Fig. 1. For our purposes, we can measure the potential difference from a set point to a number of points in a region to check if that area is an equipotential region(or line).

II. Methods and Materials

We used a clear 3-cup polypropylene food container (EasyFind; Rubbermaid; Atlanta, GA), $500\,\mathrm{mL}$ of tap water, and a pinch of salt to create an aqueous solution with sufficient conductivity for experiments. Voltage was applied using a power supply and two alligator leads, clipped to the side of the container using large size binder clips in the positions shown in Fig. 2. A $20\,\mathrm{cm} \times 20\,\mathrm{cm}$ measurement grid was then drawn on a whiteboard placed beneath the container, with dots marking 11 measurement points within a $10\,\mathrm{cm} \times 10\,\mathrm{cm}$ area, as shown in Fig. 2. With the power supply adjusted to provide $3\,\mathrm{V}$ applied voltage, we measured the potential at each of the 11 measurement points. This was repeated for applied voltages $3\,\mathrm{V}$, $6\,\mathrm{V}$ and $9\,\mathrm{V}$. For our measurements, we took the vertical midline (points 2, 5, and 8) as ground ($0\,\mathrm{V}$).

To estimate electric field in the x direction along the horizontal midline, we took finite differences between measurement points 4–8, using $dx = 2.5\,\mathrm{cm}$ between each, e.g.:

$$|E_{x,4-5}| = \frac{V_5 - V_4}{dx} \tag{1}$$

and similarly for points 5-6, 6-7, and 7-8.

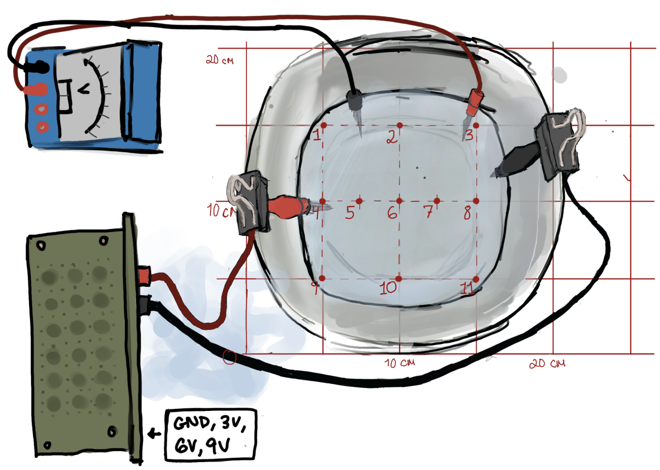

Fig. 2. Experimental setup. Tub of water depicted on right, voltmeter (blue/white) and power supply (green) on the left. Vertical midline points 2, 6, and 8 were taken as ground while horizontal midline points 4–8 were used to compute the electric field strength using finite differences, (1).

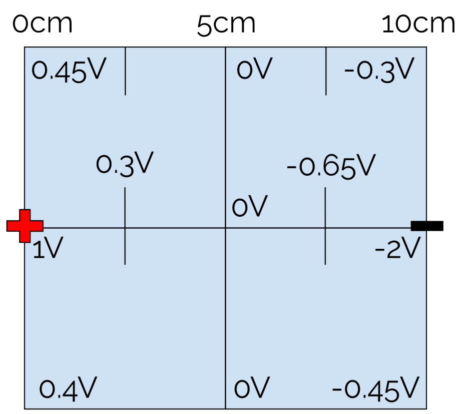

Fig. 3. Measured potentials for 3 V applied voltage shown at each test point. The test points are numbered 1–11 in Fig. 2. Positive and negative electrodes are located at the red plus and black minus signs, respectively.

III. Results

Figs. 3 to 5 show the measured potentials for three different applied voltages, 3 V, 6 V and 9 V. Table I and Fig. 6 show our estimates of the electric field along the center path between the positive and ground terminals obtained from points 4–8 using the finite difference method of (1).

Fig. 7 shows the electric fields at each point and the equipotential lines.

IV. Discussion

The electric field for this saltwater can be defined by $E = kQ(\frac{0.1}{x^2} + \frac{0.1}{0.1-x^2})$. Between $0\,\mathrm{m}$ to $0.1\,\mathrm{m}$, the distance between the two terminals, the maximum values for this equation are found at $x = 0\,\mathrm{m}$ and $x = 0.1\,\mathrm{m}$; one denominator will be 0 so $|E| = \infty$ at the (singularity) points. The minimum value is found at $0.05\,\mathrm{m}$, when the denominators are maximized. Thus

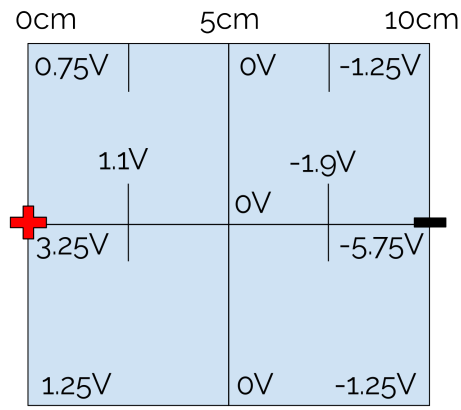

Fig. 4. Measured potentials for 6 V applied voltage shown at each test point.

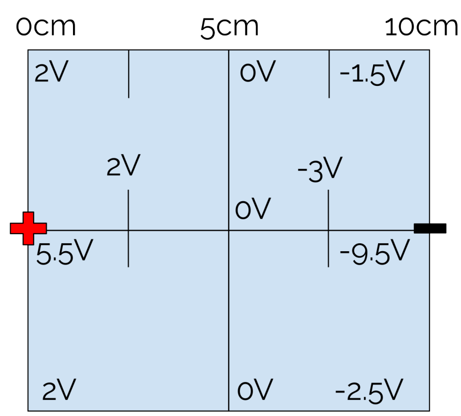

Fig. 5. Measured potentials for 9 V applied voltage shown at each test point.

TABLE I
Estimates of Electric Field Strength from the Gradient of Potential Along the Center Path Using Finite Differences for Measurement Points 4–8, (1).

	E_x, (V cm^{-1})			
V_a, (V)	points 4-5	points 5-6	points 6-7	points 7-8
9	1.40	0.80	1.20	2.60
6	0.86	0.44	0.76	1.54
3	0.28	0.12	0.26	0.54

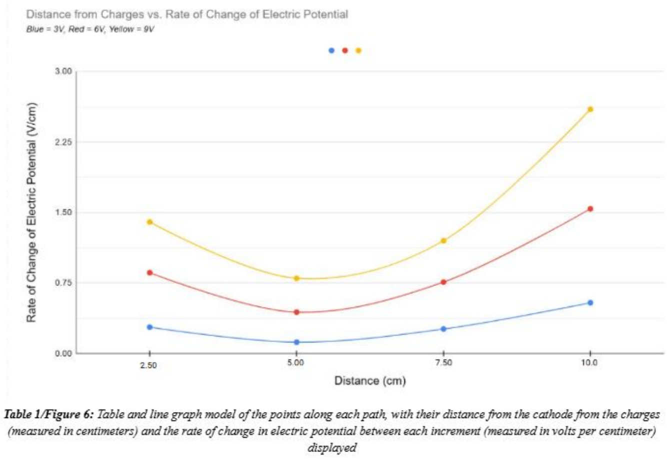

Fig. 6. Estimates of electric field strength from the gradient of potential along the center path using finite differences along measurement points 4–8, (1). Data from Table I.

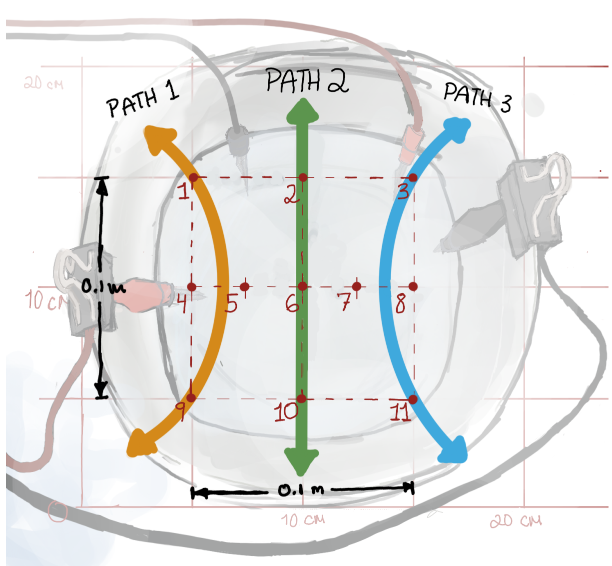

Fig. 7. Model of the tub overlaid with the observed equipotential lines and electric field lines for each point. Equipotential lines are carried in three paths (orange, green, and blue) while the electric field lines are shown as yellow arrows.

the gradient of potential observed in Table I and Fig. 6 makes sense as it follows that type of pattern, though it is odd that the rate of change seems to higher at the negative terminal than it is at the positive terminal (9 V data in Table I and Fig. 6). This is likely due to a combination of human error and errors with the system. The terminals moved around a bit while we worked, which may have changed the distance between certain points and the terminal, causing odd values. Additionally, the salt in the water may not have dissolved evenly and congregated closer to the negative terminal, increasing the relative electric field in that region since the water would be more conductive.

The equipotential lines sketched in Fig. 7 loosely match the shapes predicted for a dipole as shown in Fig. 1. We can see that, with a small margin of error, the top and bottom left points for each of the different voltages are the same. These form an equipotential line which makes sense as both have the same distance to the positive and ground terminals, so they will both be affected by the terminals electric fields in the same way. This goes for the top and bottom right points and the center line between the terminals for each voltage as well. We can also see that as the left clasp gave off a positive charge and the right clasp gave off a negative charge, the electric fields at each point pointed away from the cathode and gradually started to point more toward the anode as they got closer to it, following the path of electric fields from positive to negative. Though some of the potential values were a little different between supposed equipotential regions, this can be explained by human error. For the same reasons why the tested rate of change for potential was a little off.

By analyzing the data, we observed that the electric field strength (e.g. see Fig. 6) follows what is essentially an inverse quadratic function that has approached infinity at $x = 0\,\mathrm{m}$ and $x = 0.1\,\mathrm{m}$ and has a minimum in the middle. This observation aligns with what we expected from theory, as the electric field is the derivative of potential and this is the same form as the electric field for two-point charges. We also identified three equipotential lines located along the paths between the top and bottom right, the top and bottom left, and directly between the two charges. We had a few errors that skewed our data, but did not entirely reject our hypothesis as the areas where we did not make significant errors were extremely consistent with our expected results. These errors mainly had to do with the terminals of the power supply shifting around in the water and possibly with the salt not dissolving evenly in the water, Ideally, the experiment would be conducted with the terminals of the power supply affixed onto the container, as opposed to just being clamped down, and with the water stirred well so that the salt would be fully and evenly dissolved into it. Also a voltmeter with higher precision would be useful, since more exact data is better data. Despite the lack of optimization, this experiment shows that saltwater is a reasonable low cost solution for an electrophoresis rig as it can properly construct equipotential regions.

V. Acknowledgement

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VK set up and performed experiments, and worked on introduction, formatting, and revisions. SB set up and processed and plotted results from the experiment, and worked on abstract and conclusions. PT set up and performed experiments and worked on abstract and conclusions. DA set up the lab and plotted results, and worked on abstract and materials and methods. NM set up and performed experiments, plotted results, and worked on the results section.

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