PHYSICS 202 LAB 2: MAPPING THE ELECTRIC FIELD OF AN ELECTRIC DIPOLE
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THEORETICAL DISCUSSION

Electric Forces and Fields: The electric force between two point charges q_1 and q_2 located a distance r apart, is equal to

$$\vec{F}(q_1, q_2, \vec{r}) = k\frac{q_1 q_2}{r^2}\hat{r} = \frac{q_1 q_2}{4\pi\varepsilon_0 r^2}\hat{r}$$

where the charges q_1 and q_2 are in Coulombs, r is the distance in meters between the charges and

$$\varepsilon_0 = \frac{1}{4\pi k} = 8.85\times 10^{-12}\ \mathrm{C/N\cdot m^2}$$

is the permittivity of free space. The direction of the force (given by the unit vector $\hat{r}$) lies along the line connecting q_1 and q_2 and is repulsive if both charges have the same sign and attractive if the charges have opposite signs.

We can, if we wish, make an arbitrary distinction between q_s, which we will call the *source charge* and q_t, which we will call the *test charge*, and suppose that the source charge creates an electric field which will exert a force on any test charge q_t we place within it's range (which is infinite, as a matter of fact).

The electric field $\vec{E}$ due to a source charge q_s at a field point located a distance r away from q_s, is

$$\vec{E}(q_s, \vec{r}) = k\frac{q_s}{r^2}\hat{r} = \frac{q_s}{4\pi\varepsilon_0 r^2}\hat{r}$$

so that $\vec{F}(q_s, q_t, \vec{r}) = q_t\vec{E}(q_s, \vec{r})$, and likewise $\vec{E}(q_s, \vec{r}) = \frac{1}{q_t}\vec{F}(q_s, q_t, \vec{r})$.

The electric field due to a collection or set of source charges $\{q_j\} = q_1, q_2, \ldots, q_n$ is the vector sum of the fields due to each of them individually, so that

$$\vec{E}(\{q_j\}, \vec{r}) = \sum_{i=1}^{n}\vec{E}(q_i, \vec{r}) = \vec{E}(q_1, \vec{r}) + \vec{E}(q_2, \vec{r}) + \cdots + \vec{E}(q_n, \vec{r})$$

A test charge q_t placed at the field point $\vec{r}$ will experience a force

$$\vec{F}(\{q_j\},q_t,\vec{r}) = q_t\vec{E}(\{q_j\},\vec{r}) = q_t\sum_{i=1}^{n}\vec{E}(q_i,\vec{r}) = q_t\left[\vec{E}(q_1,\vec{r}) + \vec{E}(q_2,\vec{r}) + \cdots + \vec{E}(q_n,\vec{r})\right]$$

In this experiment, a pair of electrodes are placed in a bath of salt water. The source charges on the electrodes create an electric field. Salt water is a good conductor, which means that it has a relatively large number of mobile charge carriers. These charge carriers play the role of test charges. They will experience a force due to the field created by the electrodes and will be accelerated. The moving test charges constitute an electric current, which flows in the direction of the electric field[1].

> *The (immobile) charge on the electrodes creates an electric field, which causes the (mobile) charges in the water to accelerate, thereby creating a current in the water.*

Electric Potential Energy and Electric Potentials: When a force accelerates a particle through some distance, it does work on the particle, changing its potential energy U. The differential change in electric potential energy δU of a charged particle as it moves through a differential displacement $\delta\vec{s}$ is equal to[2]

$$\delta U = -\vec{F}\cdot\delta\vec{s} \qquad \textbf{Eqn. 1}$$

If the force and the differential displacement are perpendicular to one another, then according to the definition of the dot product, the differential change in potential energy is zero[3]; i.e.,

$$\text{If } \delta U = \vec{F}\perp\delta\vec{s}\text{, then } \delta U = 0$$

A very important consequence of this equation is that *the potential energy of a particle does not change as you move it along a curve which is perpendicular to the direction of the force*. This is true of all forces, not just electric forces.

In analogy with the relationship between the electric force and the electric field—the electric field is the force of a configuration of source charges on a test charge, per unit test charge,—we define the *electric potential V* as the electric potential energy of a test charge due to a source charge configuration, per unit test charge. Since $\vec{E} = \frac{1}{q_t}\vec{F}$, and $V = \frac{1}{q_t}U$, dividing both sides of equation 1 by the test charge q_t gives the relation

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[1] Because the charge carriers in this case are positive. If they were negative, the current would flow *opposite* the direction of the electric field.
[2] This is true for *all* forces, not just electrical forces.
[3] Because the scalar product of any two perpendicular vectors is zero.

between the change in electric potential dV between two points in an electric field $\vec{E}$ connected by a differential displacement vector $d\vec{s}$:

$$dV = -\vec{E} \cdot d\vec{s}$$

It follows that the electric potential doesn't change along a curve perpendicular to the direction of the electric field. The curves along which the electric potential V is constant are called *equipotential lines*. Furthermore, since current flows in the direction of the electric field, and equipotential lines are everywhere perpendicular to this direction it follows that no current flows along lines of equipotential.

EXPERIMENTAL PROCEDURE

Synopsis

- We set up an electric field in a bath of salt water by placing positive and negative electrodes in it
- We map the equipotential lines by finding curves along which no current flows.
- We map the electric field by drawing lines connecting the electrodes that intersect the equipotential lines at right angles.

Detailed Instructions:

1. Make sure that your pan contains a plotting sheet. Cover the sheet with a thin layer of water.
2. Place the positive and negative electrodes on the circles on your plotting sheet. Your instructor will check the circuit before turning up the voltage.
3. Place the stationary probe at the first of the square stationary probe marks. An electric circuit connects this probe through a galvanometer (current meter) and a moveable probe. When current flows through this circuit, the galvanometer will register it; as the current goes to zero, the galvanometer reading will go to zero also. By searching with the moveable probe for points of zero current, and marking them on the plotting sheet, you can map out an equipotential line.
4. As you locate each point of zero current in your pan, mark this location on your individual sheet of graph paper.
5. Repeat this procedure for each of the stationary probe locations (see fig. 1a–1c). The example below shows three lines of equipotential, **but you will make seven of them. (Seven, do you hear me? That means draw 7 equipotential lines).**

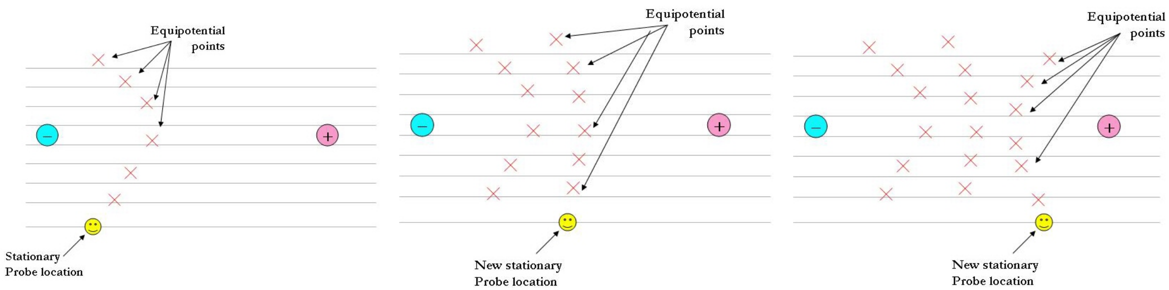

Fig. 1a **Fig. 1b** **Fig. 1c**

Fig. 1: Mapping out the points of equipotential

6. This will give you a family of equipotential lines, which you create by drawing the best smooth curve through each family of equipotential points. **Do not merely connect the dots!!** See figure 2.

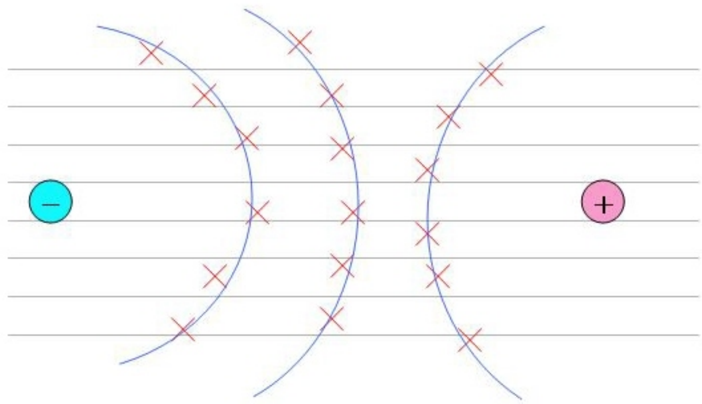

Fig. 2: Drawing the equipotential curves

7. Map the electric field lines as follows (see figure 3):

    a. Your first field line will be the straight line connecting the electrodes.

    b. Sketch additional lines by estimating the points at which a particular line will cross the equipotential curves at right angles, and connecting these points.

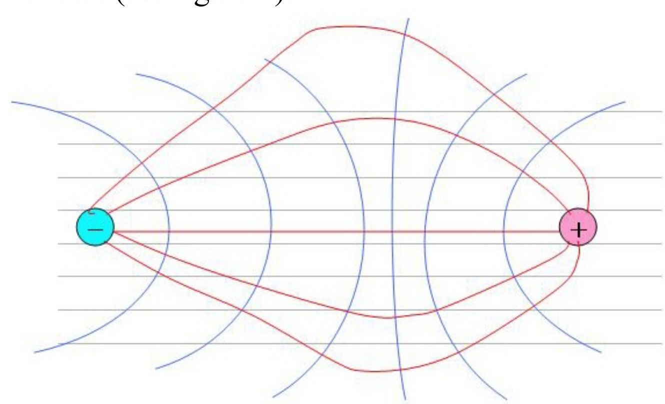

Fig. 3: Mapping the Field Lines

8. Sketch at least 6 field lines symmetrically about the central line (three above and three below). This will require you to draw a total of six (that is, 6) field lines.