The Electric Field around a Dipole

Theory

The field concept is a useful construct for forces that act over a distance. For example, Object 2 is subject to a gravitational force from Object 1. This can be viewed as Object 2 being influenced by the gravitational field established in space by Object 1. Similarly, electric charges establish electric fields in the space surrounding them.

Figure 1 shows the orientation of the field surrounding isolated point charges. It is radially directed (like gravity), but can be inward or outward depending on the sign of the charge (gravity is of course always attractive).

The lines in the figure are called field lines, and have the following properties:

- They originate on positive charges and terminate on negative charges (or at infinity).
- Arrows show the direction of the field.
- The magnitude of the field is indicated by the density of the lines; closer together, the field is stronger than when the lines are spaced farther apart.

The value of the electric field $E$ at any point around an isolated point charge $q$ is given by

$$
\vec{E} = \frac{k|q|}{r^2} \hat{r}
$$

where $r$ is the distance between $q$ and the point in question. As you can see, $E$ is a vector, with magnitude as well as direction (the $\hat{r}$ in Equation 1 is just the unit vector in the radial direction). It has units N/C.

If more than one charge is present in a region of space, then the total electric field at any point is the superposition of the fields from each individual charge.
\[ \vec{E}_{TOTAL} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots \]

Figure 2 shows the electric field due to a pair of equal and opposite charges, known as an electric dipole.

![Figure 2: Electric Field Around a Dipole](image)

Intimately related to the electric field is the concept of electric potential. If a charge is displaced an amount \( x \) in an electric field, the work that must be done is given by

\[ W = (F \cos \theta)x = (qE \cos \theta)x \]

where \( \theta \) is the angle between the force \( F \) and displacement vectors. The electric potential \( V \) is defined as the ratio of this work to the charge magnitude

\[ V = \frac{W}{q} \]

and has units J/C (called a volt, V). As you can see, if the charge is moved perpendicular to the electric field, there will be no work done \( (\theta = 90^\circ) \), and therefore no potential difference between where you started and where you stopped. In other words, both of these points would be at the same potential. A collection of such points is called an equipotential line, and are shown in Figure 2 along with the field lines.

We will exploit this relationship between the equipotential and field lines in this experiment, as equipotential lines are easy to find with a voltmeter. Once the equipotential lines around the dipole are found, the electric field lines can be plotted by following these rules:

- Electric field lines originate on positive charges and terminate on negative charges (or at infinity).
- Electric field lines cross equipotential lines only at right angles \( (90^\circ) \).

**Apparatus**

Field mapping apparatus, Conducting sheet, Power supply, DMM, Probe, Connecting wires.
Procedure

The field mapping apparatus listed above is actually a misnomer, as we will use it to find equipotential lines, not electric field lines directly. It consists of a numerically gridded conducting sheet atop an acrylic board to which are affixed a pair of metal washers. These washers are the “point” charges (somewhat larger than points to assist in establishing the needed potential difference across the sheet). When connected to a power supply, the DMM (voltmeter) can be used to find a collection of points at the same potential; i.e., on the same equipotential line.

1. You will be given a printed copy of the conducting paper on which to record your data. Indicate the position of the point charges on this sheet. The positive charge is the connected to the positive (red) side of the power supply; the negative charge to the negative (black) side.

2. Connect the COM lead of the DMM to the negative charge; the positive lead (V/Ω) will act as a probe. It should be set to measure potential (voltage) - scale it to 20VDC. Since we have not worked with electrical connections or meters yet, have your lab instructor check the connections before proceeding.

3. Calculate 15% of the power supply voltage (+10V or +12V). This is the first equipotential line you will find.

4. Take the probe and move it around on the conducting paper until the DMM measures the potential you calculated in Step 3 (anything in the range ± 0.02V is fine). Record the position of the probe on your sheet. Move the probe ≈ 1cm away from this point until you locate another point at this potential and record its location. Continue this process until you end up back where you started (a closed loop) or run off the conducting paper (in this case, go back to your original point and continue on the opposite side).

5. Since all of the points you found are at the same potential, they are on an equipotential line. Draw a smooth curve through the points.

6. Repeat Steps 4 - 5, finding the equipotential lines corresponding to 30%, 50%, 70%, and 85% of the power supply voltage. You will notice that the lines will bend more the closer you are to a charge; here, you should stick to ≈ 1cm between the points you find. As the lines get straighter you can increase this distance to a few cm.

7. You are done with data collection. Turn off the DMM and power supply.

Analysis

1. Your coordinate sheet now has the location of the point charges, the equipotential points you found, and the equipotential lines you plotted. On this same sheet, plot the electric field lines around the dipole, using the rules given in the Theory section. Be sure to indicate direction! Construct enough lines so that the field is shown in all areas.

2. Choose a point on one of your electric field lines and mark it on your sheet. This point should not be on the dipole axis (the line connecting the charges) or its perpendicular bisector; i.e., no symmetry allowed. What you are going to do is calculate the magnitude and direction of the electric field vector at this point. You will then compare this to the direction given by the field line (the electric field vector at a point is always tangent to the field line at that point).

3. In Table 1, record the coordinates of the point charges and the coordinates of the point you chose. Since this is a dipole, you know that the charges on the paper are equal and opposite - pick a charge magnitude (e.g., $q = \pm 1\, \mu C$).
4. Calculate the magnitude of the electric field vector $|\vec{E}_+|$ at your point due to the positive charge using Equation 1. Since you have the coordinates of both points, first use the Pythagorean theorem

$$ r = \sqrt{x^2 + y^2} $$

to calculate $r_+$, the distance between the positive charge and your point.

5. You now need the direction of this vector. Use the relation

$$ \tan \theta = \left| \frac{y}{x} \right| $$

and remember that this gives you reference angle only! Draw the vector on your coordinate sheet.

6. Calculate the $x$ and $y$ components of the vector.

7. Repeat Steps 4-6 with the negative charge.

8. Calculate the total (resultant) electric field vector $\vec{E}_R$ at your point, and draw this vector on your coordinate sheet.

9. How does the direction of your calculated field compare with the direction obtained from the field mapping?
## Table 1

### Data and Calculations

<table>
<thead>
<tr>
<th>Coordinates of positive charge (m)</th>
<th>Coordinates of negative charge (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordinates of field point (m)</td>
<td></td>
</tr>
<tr>
<td>Charge magnitude (C)</td>
<td></td>
</tr>
</tbody>
</table>

### Positive Charge

| $r_+$ (m) | $|\vec{E}_+|$ (N/C) | $\theta_+$ ($^\circ$) | $E_{+x}$ (N/C) | $E_{+y}$ (N/C) |
|-----------|---------------------|-----------------------|----------------|----------------|

### Negative Charge

| $r_-$ (m) | $|\vec{E}_-|$ (N/C) | $\theta_-$ ($^\circ$) | $E_{-x}$ (N/C) | $E_{-y}$ (N/C) |
|-----------|---------------------|-----------------------|----------------|----------------|

| $E_{Rx}$ (N/C) | $E_{Ry}$ (N/C) | $|\vec{E}_R|$ (N/C) | $\theta_R$ ($^\circ$) |
|----------------|----------------|---------------------|----------------------|


Pre-Lab: The Electric Field around a Dipole

Name ___________________________ Section _____

Answer the questions at the bottom of this sheet, below the line - continue on the back if you need more room. Any calculations should be shown in full.

1. What is an electric field?
2. What is an equipotential line?
3. What are the rules for obtaining electric field lines from equipotential lines?
4. Calculate the electric field vector (magnitude and direction) at Point $P$.

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[Diagram showing a dipole with $+50.0 \mu C$ and $-50.0 \mu C$ charges, with a point $P$ 50.0 cm above the dipole.]