OPERATING INSTRUCTIONS

Overbeck Electric Field Mapping Apparatus
No. 79587

1. Introduction
The Overbeck Electric Field Mapping Apparatus (79587) is used to map equipotential lines of an electric field and locate the electric lines of force.

2. Theory
2A. Coulomb’s Law: The first quantitative investigation of the law of force between electrically charged bodies was carried out by C. A. Coulomb in 1784-1785. His measurements showed that the force of attraction for unlike charges or of repulsion for like charges followed an inverse square law of distance of separation. It was later shown that for a given distance of separation \( r \) the force is proportional to the product of the individual charges, \( Q \) and \( Q' \), and is a function of the nature of the medium surrounding the charges. Expressed mathematically, Coulomb’s Law is:

\[
F \propto \frac{QQ'}{Kr^2}
\]

where the factor \( K \), called the dielectric constant is introduced to take care of the nature of the medium. The factor \( K \) is arbitrarily assigned a value of 1 for empty space. Coulomb’s Law is restricted to point charges, that is, the charged body must have dimensions that are small compared to the separation distance.

2B. Systems of Units: Several systems of units, each with its particular advantages are in use. The electrostatic system is emphasized here. In the electrostatic system, forces are expressed in dynes, distances are expressed in centimeters, and the unit of charge (called the statcoulomb) is chosen of such magnitude that the proportionality constant in Coulomb’s Law is equal to unity. Thus, Coulomb’s Law can be expressed by:

\[
F = \frac{QQ'}{Kr^2} \quad (1)
\]

2C. Unit Quantity of Electricity or Charge: When all quantities in equation (1) are unity the definition of the electrostatic unit (esu) of charge or statcoulomb is indicated — *The statcoulomb is a charge of such magnitude that it is repelled by a force of 1 dyne when placed 1cm from an equal charge in a vacuum.* The charge of one electron is a natural basic unit of quantity of electricity. Its charge is \( 4.80 \times 10^{-10} \) statcoulomb. Thus 1 statcoulomb represents a charge of \( 2.09 \times 10^9 \) electrons or approximately two billion electrons. For practical use, however, the statcoulomb is exceedingly small and a charge known as the coulomb or ampere-second is used. The coulomb is approximately equal to three billion statcoulomb.

2D. Dielectric Constant: The factor \( K \) in Coulomb’s Law, called the dielectric constant of the medium, is assigned a value of 1 for a vacuum. When the medium separating the charges is not empty space, the force between the charged bodies is altered because charges are induced in the molecules of the medium. Air at one atmosphere pressure has a dielectric constant of 1.00059. Thus as a practical matter, equation (1) using \( K = 1 \) is acceptable to one part in two thousand for Coulomb’s Law experiments in air.
The common dielectrics have “constants” $K$ from 1 to 10 in value. The dielectric constant of glass ranges from 5 to 10, mica from 3 to 6, and oil from 2 to 2.5. The specific value of the “constant” for a given medium may vary with a change in temperature, pressure, frequency of current, etc. Also note that $K$ is not a pure number but has dimensions dependent on the system of units used.

2E. Electric Fields: An electric field, commonly called field of force, is a region in which forces act on electric charges if present. If a force $F$ acts on a charge $q$ at a point in the field, the field strength $E$, by definition the force per unit charge, is:

$$E = \frac{F}{q} \quad (2)$$

that is, the magnitude of electric field strength is the force per unit charge. Force is a vector quantity having direction as well as magnitude. The direction of an electric field at any point is the direction of the force on a positive test charge placed at the point in the field.

2F. Lines of Force: Faraday introduced the concept of lines of force to visualize the strength and direction of an electric field. A line of force is the path that a free test charge would follow in traversing the electric field. The path is everywhere tangent to the field direction at each point. As an illustration, consider the isolated positive charge $Q$ placed at $A$ in Figure 1. A small positive test charge $q$ at any point in the field experiences a radial force of repulsion from $A$. The lines of force are drawn with arrows to point this direction. When $Q$ is a negative charge, that is an excess of electrons, these lines would be directed towards $A$ to indicate an attraction of the positive test charge $q$.

![Figure 1 Electric field around an isolated positive charge.](image)

The magnitude of the force per unit charge may also be graphically shown by the artifice of lines of force. By convention, the number of lines of force drawn through a unit area placed normal to the field at the point considered, is made numerically equal to the field strength. For example, if the field strength at a point is 5 dynes per statcoulomb, one visualizes five lines of force per square centimeter at that position in the field.

The diagram of Figure 2 shows a plane section near a pair of equal charges of opposite sign. Each charge exerts a force on a unit test charge placed in the field. The resultant force is the vector sum of these forces. Thus, at the point $b$, $f_1$ is the repulsion force on the unit test charge due to the positive charge on $A$, and $f_2$ is the force of attraction to the negative charge on $B$. The resultant $R$ is tangent to the line of force at the point $b$. 
It is evident that a uniform field is represented by a set of parallel lines of force. A converging set of lines of force indicates a field of increasing strength; while a field of decreasing strength would be represented by a diverging set of these lines.

2G. Potential Difference: Two points in an electric field have a difference of potential if work is required to carry a charge from the one point to the other. This work is independent of the path between the two points. Consider the simple electric field illustrated in Figure 3.

Since the charge $+Q$ produces an electric field, a test charge $+q$ at any point in the field will be acted upon by a force. It will be necessary to do work to move the test charge between any such points as $B$ and $C$ at different distances from the charge $Q$. The potential difference between two points in an electric field is defined as the ratio of the work done in moving a small positive charge between the points considered to the charge moved — symbolically stated:

$$V = \frac{W}{q} \quad (3)$$

where $V$ is the potential difference, $W$ is the work done, and $q$ is the charge moved. In the electrostatic system $B$ is expressed in statvolts when $W$ is in ergs and $q$ in statcoulombs. One statvolt is approximately equal to 300 volts. If the work $W$ is measured in joules and the charge $q$ in coulombs then the potential difference $V$ is measured in volts.

The conservation of energy principle requires that the work done must be independent of the path over which the charge is transported. Otherwise energy could be created or destroyed by moving a charge from one point such as $B$ in Figure 3 to $C$ by path $a$, involving a certain energy, and returning by path $b$ of different energy.
2H. Absolute Potential: If point B in Figure 3 is taken very far from A, the force on the test charge q at this point would be practically zero — see equation (1). The potential difference between C and this point at an infinitely large distance away is called the absolute potential of point C. The absolute potential of a point in an electric field may, therefore, be defined numerically as the work per unit charge required to bring a small positive charge from a point outside the field to the point considered. Since both work and charge are scalar quantities, it follows that potential is a scalar quantity. The potential near an isolated positive charge is positive, while that near an isolated charge negative. (What is the physical significance of negative work?)

2I. Equipotential Surfaces: It is possible to find a large number of points in an electric field, all of which have the same potential. If a line or a surface is so drawn that it includes all such points, the line or surface is known as an equipotential line or surface. The line C'C' in Figure 4 is an equipotential line. A test charge may be moved along an equipotential line or over an equipotential surface without doing any work.

2J. Lines of Force Perpendicular to Equipotential Surfaces: Since no work is done in moving a charge over an equipotential surface it follows that there can be no component of the electric field along an equipotential surface. Thus the electric field or lines of force must be everywhere perpendicular to the equipotential surface. Equipotential lines or surfaces in an electric field are more readily located experimentally than lines of force, but if either is known the other may be constructed as shown in Figure 5. The two sets of lines must everywhere be normal to one another.
The field in Figure 4 is a reproduction of an actual test made in designing a part for a high voltage generator. The solid lines are the equipotential lines and the dash lines are the lines of force for a field existing between a pin and a plane.

2K. Potential of a Conductor: Electrons in a conductor can move under the action of an electric field. Thus, if an electrical conductor is placed in an electric field, this electron flow, which constitutes an electric conductor will take place until all points in the conductor reach the same potential. There will be no net electric field inside the conductor whether solid or hollow provided it contains no insulated charge. Thus, to screen a region of space from an electric field it need only be enclosed within a conducting container since all parts of the conductor are at the same potential, the electric lines of force always leave or enter the conductor at right angles to its surface.

2L. Lines of Flow: When charged bodies of different potentials are located in a medium in which some flow of charge can occur, the field of force will cause these charges to be transported from one body to the other. To maintain the difference of potential the bodies must then be connected to a source of electromotive force. The flow lines of the charge follow the paths of the lines of force, that is, they are also at all points perpendicular to the equipotential surfaces.

3. Description
The apparatus consists of a field-mapping board, a U-shaped probe, six field plates (pictured in Figure 6), and two plastic templates. The patterns on the two templates are a composite of the patterns on the six field plates. Any one of the six field plate patterns can be reproduced with the templates. Eight similar resistors are connected in series between the two binding posts on the field-mapping board to eight points separated by the same difference of potential.

4. Setup
The following equipment is required for operation:

   a. A source of potential, such as a 2V or 6V battery or the RF Signal Generator (80595-05).

   b. A null-point detector, such as a pair of headphones (80785) used in conjunction with the RF signal generator, or a galvanometer (82101-01) used in conjunction with the battery.

Turn the field mapping board over and notice the two metal bars. Each bar has two threaded holes. Two of these holes hold plastic-headed thumb screws with knurled lock nuts. Remove the thumb screws and center any one of the field plates so the holes in the plate coincide with holes in the metal bars. Insert a thumb screw into each hole and turn it until it touches the board below. Turn the knurled lock nut to hold the field plate securely in place.

Binding posts marked “Bat.” and “Osc.” are located on the upper side of the board. Connect the potential source to the appropriate binding post. Fasten a sheet of 8.5 x 11-inch graph paper to the upper side of the board. Secure the paper by depressing the board on either side and slipping the paper under the four rubber bumpers. Select the design template containing the field plate configuration you have chosen. Place the design template on the the two metal projections (template guides) above the paper edge and let the two holes on top of the template slide over the projections. Trace the design corresponding to the field plate pattern in place on the underside of the mapping board and remove the template.
5. Operation

Place the Field Mapping Board and the U-shaped probe on a lecture table or laboratory bench.

Carefully slide the U-shaped probe onto the mapping board with the ball end facing the underside of the filed mapping board. Connect one lead of the null-point detector (galvanometer or headphones) to the U-shaped probe and one to one of the banana jacks, numbered E1 through E7.

Notice the knurled knob on top of the probe (next to the spotting hole) and the screw below the probe that acts as a support leg. To make tracings, guide the probe with one finger of one hand resting lightly on the knurled knob, and a finger on the other hand lightly touching the nut of the leg. The leg slides on the table top and stabilizes the probe. Do not apply pressure to the probe, and avoid squeezing its jaws. This causes unnecessary wear on the plates. Although some wear is inevitable, the plates will last longer if proper care is taken.

Using the selected banana jack, move the U-shaped probe over the paper to a zero reading or a no-sound position. The circular hole in the top arm of the probe is directly above the contact point that touches the graphite-coated paper. Record the location of the equipotential point directly on the paper. Move the probe to another null-point position and record it. Continue this procedure until you have generated a series of these points across the paper. Connect the equipotential points with a smooth curve to show the equipotential line of the banana jack.

Connect the detector to a new banana jack and plot its equipotential line. Repeat until equipotential lines are plotted for all banana jacks E1 through E7. Since the potential difference is the same across each similar resistor, the equipotential lines will be spaced to show an equal potential drop between successive lines.

The lines of force are perpendicular to these equipotential lines at every point. Using dashed lines, draw in the lines of force of the electric field being studied. After completion, select a different field plate and repeat the above procedure until all electric fields from the six field plates (shown in Figure 6) are drawn.

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**Figure 6 The Overbeck Electric Field Mapping Apparatus' six field plates.**
6. Questions

1. Why are the equipotential lines near conductor surfaces parallel to the surface and why perpendicular to the insulator surface mapped?

2. Is it possible for two different equipotential lines or two lines of force to cross? Explain.

3. Explain, with the aid of a diagram, why lines of force must be at right angles to equipotential lines.

4. Under what conditions will the field between the plates of a parallel plate capacitor be uniform?

5. How does the electric field strength vary with distance from an isolated charged particle?

6. Sketch the equipotential lines for an isolated negatively charged particle, spacing the lines to show equal difference of potential between lines.

7. Compare the sketch in answer to Question 6 with the mapped field of the "Parallel Plate Capacitor." Account for the difference.

8. Show that the electric field strength is equal to the potential gradient.

9. What conclusions can you draw about the field strength and the current density at various parts of sheet II, Figure 6.

10. How much work is done in transferring an electrostatic unit of charge from the one terminal to the other terminal in this experiment?

11. Explain the lack of symmetry in the field of sheet I, Figure 6.

12. Sketch the field pattern of two positively charged small spheres placed a short distance from each other.

13. Explain the pattern of the field found inside a Faraday "Ice Pail."

7. Maintenance

After many hours of operation, the silvered surface of the field plates can rub off. This surface can be renewed with any high-quality conductive silver paint, such as the paint sold by radio parts dealers for repairing printed circuits. Occasionally buff the tip of the brass ball probe with a very fine grade of emery paper to ensure good electrical contact.

If difficulties arise with this apparatus that cannot be eliminated by the above steps, please contact Central Scientific Company, giving details of the problem. To ensure better service, please do not return any item to Central Scientific Company until we have sent you authorization.
8. Accessories
The following is a list of equipment suitable for use with the Overbeck Electric Field Mapping Apparatus (79587):

<table>
<thead>
<tr>
<th>Description</th>
<th>Cat. No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid State RF Signal Generator</td>
<td>80595-05</td>
</tr>
<tr>
<td>Double Headphones</td>
<td>80785</td>
</tr>
<tr>
<td>Student Galvanometer</td>
<td>82108-01</td>
</tr>
<tr>
<td>Rectangular Graph Paper, 8.5 x 11 inches</td>
<td></td>
</tr>
<tr>
<td>5 lines/cm, 100 sheets</td>
<td>72711-55</td>
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<tr>
<td>10 lines/ inch, 100 sheets</td>
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