Experiment 2-2. Equipotential Lines

- Electric Field and Gauss's Law –

**Purpose of Experiment**

By introducing the concept of electric field, we can improve our understanding about force between separated charges. If there is a charge, it produces an electric field. If there is another charge, it feels the force by the electric field. An electric field is defined as the electric force acting on a positive unit charge(+1C). Thus the electric force is proportional to the electric field with proportionality constant of the amount of charge who feels the force.

The minimum work required to move a unit charge is called the electric potential difference or just the potential difference. The minimum work means it doesn't change the kinetic energy of the charge while moving. If we choose a standard point and let the electric potential at that point to easy value(0), the electric potentials at other points are just the electric potential differences from the standard point.

The equipotential line is an imaginary line which connects the points of same potential. To move a charge along an equipotential line, the required work is 0. An equipotential line is always perpendicular to the electric force line, so that if we know it we can also see the distribution of force lines.

In this experiment, we place two electrodes on a conducting sheet, apply a potential difference between them, look for the equipotential points and obtain the equipotential lines by linking them. We also see the shapes of the equipotential lines between two electrodes.
Our aim is to see the shapes of the equipotential lines on a graphite plate in above experiment setup. A probe-attached pen is on the tablet. When the probe touches the graphite plate, it displays the potential at the point on the screen. In the screen the potentials are classified by color. A single colored line made by pen’s move means it is an equipotential line.

★ Most of experimenters would already know the shapes of equipotential lines on the graphite plate. By moving the pen along those paths, you could get more good results.
★ In this experiment the device frequently breaks down. If the probe doesn’t display the result, first of all, check the connection status. If the connection is ok, tell your teaching assistant and replace the device.
These equipments are prepared in the laboratory. (Parentheses mean the number of them.)

- graphite-coated conducting sheet (1)
- Probe-attached pen (1)
- dc power supply (0~10V, 0~1A) (1)
- input connector (1)
- computer (1)
- Circular electrode (2)
- Stick electrode (2)
- usb memory (1, prepare individually)

If you need more stuff, inquire to your teaching assistant or experiment preparation room (19-114), or prepare yourself.

The following is a recommended experiment method.

**§.1 Measurement of equipotential lines between two electrodes**

a) Connect the electrode supports with the power supply by electric wires.

b) Place two prepared Circular electrodes on the edge of graphite plate.

☞ Measurement by multimeter shows the potential difference between two electrode supports is just the voltage applied by the power supply. Nevertheless why do we use the Circular Electrodes?

☞ A graphite plate is not a good conductor. If we change it to a good conductor such as an aluminum foil, would the result be improved?

c) Put the ends of electrode supports on the Circular Electrodes so that a potential difference is generated between two the Circular Electrodes. [video: equipotential line 1]

★ When you measure, you could get better result by pressing down the supports strongly. It is related with the advantage of the Circular Electrodes.

d) Run the program in the equipotential mode with the given voltage. In other words, the range +5V--
5V and the interval 1V are enough.

e) Draw the equipotential lines as moving the probe along the plate. [video: equipotential line 2]

★ When a voltage is applied between two ends, the voltage on the center line is 0.

★ For some devices, the potential would be not 0 at the center. That is, the potential at the center isn’t displayed on the screen. Nevertheless the equipotential would be displayed well. You could find the reason by examining the power supply.

f) In addition, you could use other (significant) kinds of electrodes or place other conductors or nonconductors on the plate.

★ The program has a function displaying the electric field. You can use it but it doesn't work well by some reason. You don't need to do it

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**Background Theory**

I. Electric Field, Potential Difference and Equipotential Lines

Electric field is a vector quantity. Let the electric field be \( E \) (V/m). It means the magnitude of the electric force a charge of +1C experiences is \( E \) (N/C) and the direction is parallel to \( E \). The electric potential difference is defined as the work required to carry a charge of +1C between the point of electric potential of \( E_1 \) and the point of \( E_2 \). To move the charge in a constant velocity, the force of equal magnitude and opposite direction to the applied force is required. Thus the potential difference is the work done by the force, which is given by

\[
\Delta U = U_2 - U_1 = \int_{r_1}^{r_2} \mathbf{E} \cdot d\mathbf{r} \tag{1}
\]

This is independent on the path of charge.

If the potentials are equal at two different points \( U_1 = U_2 = 0 \), the electric field and the displacement between them is perpendicular to each other \( (E \perp dr) \). In other words, the electric
fields on an equipotential line (or surface) which is the connection of equal potential points are perpendicular to the line (or surface). The electric field line is a continuous line which is the connection of (representation of) electric field vectors produced by charges or electrodes. An electric field line is also perpendicular to the equipotential lines (or surfaces).

(a) In uniform electric field, the field lines are parallel straight lines with constant intervals, and the equipotential lines (surfaces) are also lines with constant intervals between perpendicular to field lines. (b) For a point charge, the field lines are directed radially and it is stronger at the dense part (namely, near the charge). The equipotential lines (surfaces) are concentric circles (spheres). But notice that their gap is not uniform. (c) The field lines and the equipotential lines (surfaces) for two point charges of equal magnitude and opposite sign with tiny separation (an electric dipole). This picture is related with our experiment.

**II. Conductor and Electric Fields**

Inside a conductor with free charges, the electric field is 0 in equilibrium. When the conductor is charged, the added charges are distributed to the surface, which becomes an equipotential surface. Hence if a conductor is placed in an uniform electric field, the field lines and the equipotential lines (surfaces) are changed like below. What can we know by Gauss's law?
In this experiment where the stationary current is used, the inner electric field of a conductor is not 0. But since the conductivity of conductor is very larger than that of graphite-coated sheet, it is approximately the same case.

### Experimental Method

- Analog-to-digital converter
- Computer program (Field Touch)
- Treatment of measurement data
- Analysis method based on the graph
- Carl Friedrich Gauss - A genius mathematician who counted number before learning language