Room F10309 : Equipotential surfaces and electric field

Objectives:

1. To map the equipotential lines of 1) two parallel metal plates and 2) two parallel metal plates with hollow metallic cylinder in between.
2. To obtain the magnitude of the electric field between the two parallel plates.

Background knowledge

Charges are the sources of electric field. For **a point charge** q, the magnitude of its field at a point P at some distance r away from the charge is proportional to its charge magnitude |q|, and inversely proportional to r^2. The direction of the field at point P is radially pointing away from the charge, if it is positive, and is radially pointing towards the charge, if it is negative. For **two large parallel plates with equal but opposite charges**, the field is uniform between the plates and its magnitude is proportional to the areal charge density of the plate. The direction of the field is pointing from the plate with positive charges to that with the negative charges

We use field lines to help us visualize the field. For instance, in Figure 1 **the lines with arrows are the field lines**. 1(a) represents the system of a positive point charge, 1(b) depicts that of the two parallel plates of opposite charges, and 1(c) portrays that of a dipole. The electric field at a point has the same direction of the field line and has its magnitude proportional to the areal density of the line at that point.

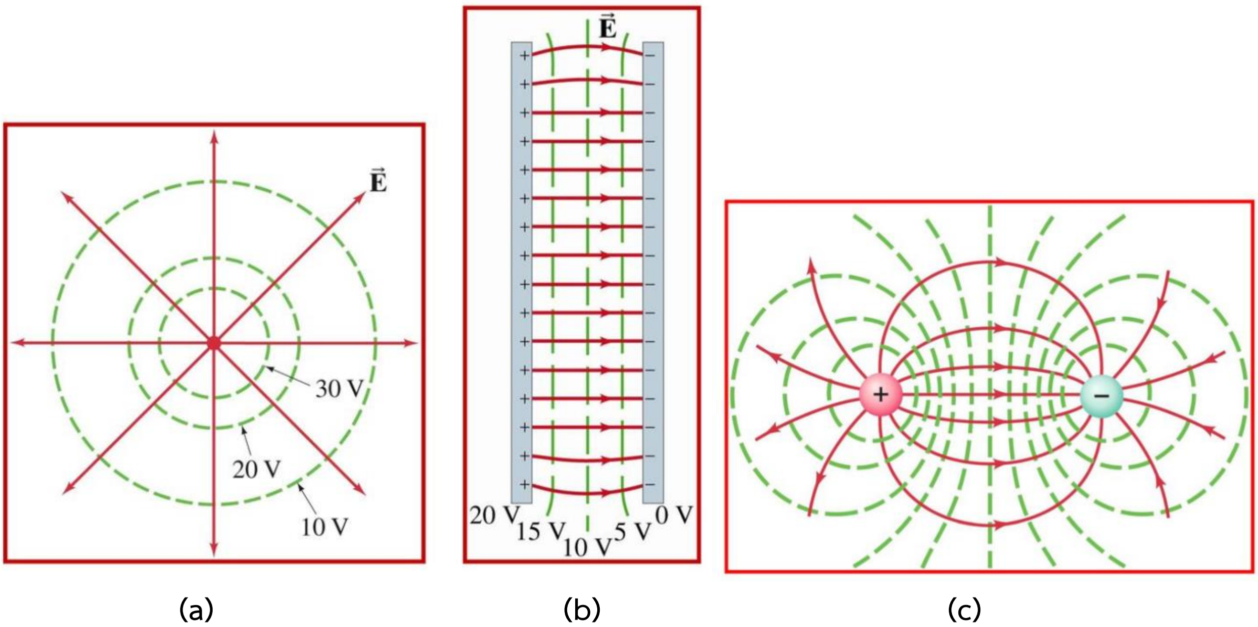


Figure 1 The filed lines (solid lines with arrows) and equipotential lines (dashed lines) of (a) a positive charge, (b) two parallel plate of opposite charges, and (c) a dipole.

Nonetheless, we do not directly measure the electric field in the lab. The quantity that we do measure directly is a voltage (difference in electric potentials of 2 points) with a voltmeter or a multimeter. We can relate the field and voltage and use it to help visualize the electric field as well. In Figure 1, all the dashed lines are called **equipotential lines**, lines of the same electric potential. Note that in 3 dimensions they are actually equipotential surfaces, surfaces of the same potential.

Quantitatively, potential difference, or voltage, ΔV between two points in space is defined as

$$\Delta V = V(\vec{r}_2) - V(\vec{r}_1) = \int_{\vec{r}_1}^{\vec{r}_2} \vec{E} \cdot d\vec{r}$$

where $\vec{E}$ is the electric field, $\vec{r}$ is a position. From this relation, we can conclude that for a equipotential surface ($\Delta V = 0$), the **field** at any point on that surface must be **perpendicular to the surface**. When we draw equipotential surfaces or lines, we do it in a way that any two consecutive surfaces or lines must have the same value of potential difference; so that **the density of the equipotential surfaces or lines is proportional to the magnitude of the field**.

In the case where the field is uniform, like the field between the two parallel plates with the opposite and equal charges in Figure 1(b), the equation above is reduced to

$$E_x = -\frac{V(x_2) - V(x_1)}{x_2 - x_1} = -\frac{\Delta V}{\Delta x}$$

where x is the position along the horizontal axis. It can be seen from this equation that the SI unit of the electric field can also be volt/meter.

Experiment

The apparatus in this lab is shown in Figure 2. It includes a clear rectangular tray with a graph paper at the bottom, a dc voltage generator, a digital multimeter or an analog multimeter, electrical wires, two metal plates, and a hollow metallic cylinder.

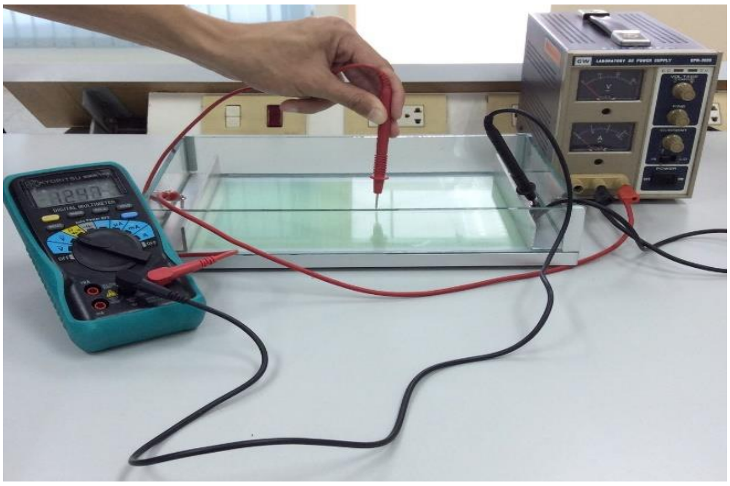
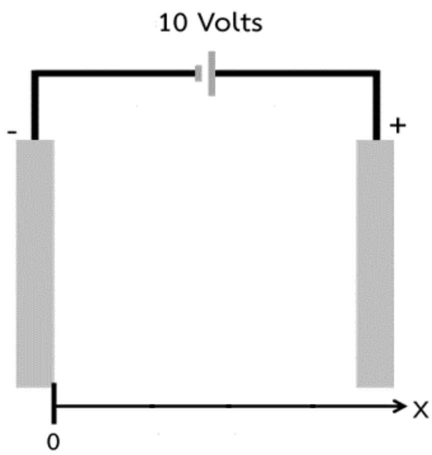


Figure 2 The lab equipment

Part 1 Two parallel plates: Place the two metallic plates at both ends of the tray and connect them to the dc generator and set the voltage to be around 10 V. Let the position of the left plate be $x = 0.00\ \mathrm{cm}$. Then, at each $x = 2.00\ \mathrm{cm}, 4.00\ \mathrm{cm}, 6.00\ \mathrm{cm}, 8.00\ \mathrm{cm}, 10.00\ \mathrm{cm}$, measure the potential difference with respect to the left plate with the multimeter. Check out the shape of the equipotential lines. Plot the potential difference vs x to obtain the magnitude of the field between the two plates.

Part 2 Two parallel plates with one hollow cylindrical metal in the middle: Do the same set up as in Part 1, only adding a hollow cylindrical metal in between the two plates. Check the shape of the equipotential lines and see if the points in the hollow cylinder have the same potential or not.



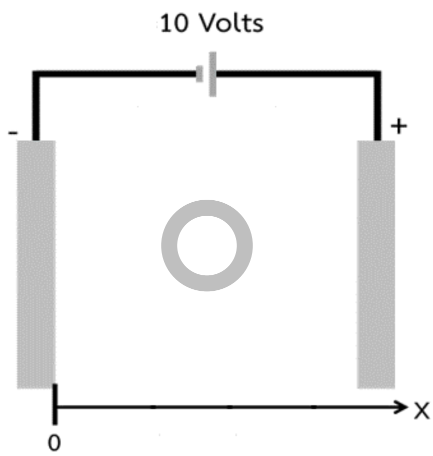


Figure 3 Diagrams for experimental set-up for Part 1 (left) and 2 (right)

Worksheet: Equipotential surfaces and electric field

Name____

Fill in the blank

The voltage or potential difference between 2 points on the same equipotential surface is equal to ____________________.

The direction of the electric field at a point on an equipotential surface is _________________ to the surface.

The SI unit of electric field is_____________________________.

Part 1: Two parallel plates

The distance between the two plates is______________________.

The potential difference between the two plates is___________________________.

Data table

x in cm (measured from the left plate) Reading error =__________	ΔV in volt Reading error =__________

After plotting ΔV (on vertical axis) vs x (on horizontal axis), I obtain

1) its slope to be____
2) its y-intercept to be____

Thus, the magnitude of the electric field between the two plates is_________________________.

Part 2: Two parallel plates with one hollow cylindrical metal in the middle

The distance between the two plates is__________________________.

The potential difference between the two plates is_______________________________.

The potential difference between the left plate and the cylinder is_______________________.

The potential difference between the right plate and the cylinder is_______________________.

The potential difference between the left plate and a point within the cylinder is________________.

Test question

Within 2 minutes, place the two metallic plates at both ends of the tray and connect them to the dc generator and set the voltage to be between 9 V and 11 V.

Full mark is 2 points.

1. When you complete the circuit, you earn 1 point. If not, you get 0.
2. When you correctly use the multimeter to measure the voltage between the two plates, you earn 1 point. If not, you get 0.