Equipotential Surfaces

Purpose

1. To be introduced to the relation between the electric field lines and the equipotential surfaces.

2. To study some cases of two point charges of opposite charges and cases of oppositely charged conductor parallel plates (parallel plate capacitor) and some other cases.

Introduction

Work done by a force, as you learned in physics 1, (see fig. 1), is the force, F multiplied by the component of the displacement, $\boldsymbol{\Delta S}$ in the direction of the force or alternatively, the component of the force, $\boldsymbol{F}$ in the direction of the displacement, multiplied by the displacement, ΔS:

$$W = F\,\Delta S\,cos\theta \qquad (1),$$

where θ is the angle between the force, $\boldsymbol{F}$ and the displacement, $\boldsymbol{\Delta S}$.

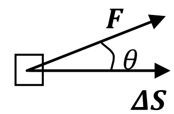


Figure 1: Work is done by a force, $\boldsymbol{F}$ when it produces a displacement, $\boldsymbol{\Delta S}$

The 'Field lines' are a convenient way to represent the electric field, $\boldsymbol{E}$. The number of the lines crossing a unit area, is proportional to the intensity of the electric field, $\boldsymbol{E}$. Whereas the tangent to the field line at a point indicates the direction of the electric filed, $\boldsymbol{E}$ at that point. See fig. 2. Also, field lines always start at a positive charge and end at a negative charge. Field lines never cross each other.

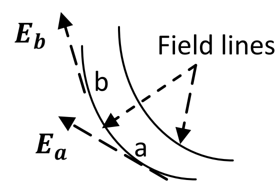


Figure 2: Filed lines and the direction of the electric field

The work done by an external force **against** a conservative force, like gravity force, is stored as potential energy. For gravity, it is called the gravitational potential energy. The electrostatic force is also a conservative force.
Therefore, the work done by an external force against the electrostatic force, $\boldsymbol{F}_e$ to move a charge, q between two points is stored as electric potential energy (or change in electric potential energy). As you learn in physics 2, the electrostatic force experienced by a charge, q, due to an electric field, $\boldsymbol{E}$ is given by the relation:

$$\boldsymbol{F}_e = q\,\boldsymbol{E} \qquad (2)$$

Using eqns. (1) and (2) the electric potential energy stored, ΔU (or the change in electric potential energy) is given by:

$$\Delta U = -qE\Delta S\,cos\theta \qquad (3)$$

The electric potential difference, ΔV between two points is defined as the work done to move a unit charge between the two points; That is the change in electric potential energy per unit charge:

$$\Delta V = -E\Delta S\cos\theta \qquad (4)$$

If $\Delta V = 0$, the two points have the same electric potential. In eqn. (4) if E and S are **not** 0, then θ must be 90^o; that is the electric filed, $\boldsymbol{E}$ is perpendicular to the displacement, $\boldsymbol{\Delta S}$ between the two points. If the two points lie on a surface and are very close to each other, then the direction of ΔS is the tangent to the surface. A surface that has the same potential for all of its points is called an 'Equipotential surface'. Therefore, for an equipotential surface, the electric field, $\boldsymbol{E}$ is always perpendicular to the tangent to the surface. The surface of a conductor is always equipotential. a) Why?

If we can determine the surface that has the same electric potential, the equipotential surface, then we can also draw the field lines, because they are simply lines perpendicular to tangents to that surface at all its points. Notice that in two dimensions the equipotential surfaces appear as lines or curves.

Running the experiment **(the data sheet is on pages 5 and 6)**

Part 1: Equipotential surfaces for two oppositely charged point charges

1) Open the simulator https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html

Check the option Grid at the top right of the screen. The Grid is nearly 16 (horizontal) by 10 squares (vertical), (ignore the fraction of the square on the left and on the right and count the top square as a complete square and also the bottom square as a complete square). We will assume that the origin of the grid, $(0,0)$ is at the center of the grid of the simulator. Each complete square is considered a 1 unit of coordinate. So, count 8 squares from the left and 5 squares from the top and the origin will be there at the center of the grid.

2) Click and drag the point charge, $q_1 = +1nC$ to point $(-4,0)$ on the grid. Click and drag the point charge, $q_2 = -1nC$ to the point $(4,0)$ on the grid. So the two charges are now separated by 8 squares.

Notice the arrows represent the vectors of the electric field due to the two charges. A bright arrow means large intensity of the electric field and a dim arrow means low intensity of the electric field.

3) Do you expect the vertical line at $x = 0$ to be an equipotential?

4) Now let's check. At the right hand side of the simulator there is a voltmeter 

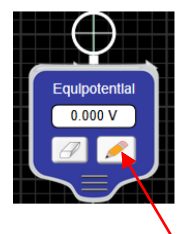
click and drag it so that the $+$ cross hair mark of the top of the voltmeter is at the center of the grid, the point $(0,0)$. Now click and drag the voltmeter to the point $(0, 1)$.

a) Does it read nearly the same electric potential?

Click and drag the voltmeter to the point $(0, -1)$.

b) Does it read nearly the same value of electric potential?

5) Now click the pencil icon on the voltmeter, as shown in fig. 3. The simulator will draw the equipotenial surface. Was your expectation correct?



pencil

Figure 3: Pencil of voltmeter

6) Now by clicking and dragging the voltmeter search for a point where the electric potential is nearly 6 v. What are the (x, y) coordinates of the point on the grid?

7) Now click the pencil icon on the voltmeter. The simulator will display the curve for all the points that has a voltage of 6v, that is, the equipotential surface for the 6 v value.

8) Repeat steps 6 and 7 for the points where the electric potential, V is nearly equal to 15 v, then, 2.4 v, 1 v, -1 v, -2.4 v, -6 v and finally -15 v. Record in the table for step 8 of part 1 in the data sheet.

9) Now check the option **'Values'** on the top right of the simulator screen. This will display the electric potential (voltage) values on the grid. Print screen and save and keep to submit with your lab report.

Part 2: Field lines for a parallel conductor plates (parallel plate capacitor)

1) Open the simulator https://phet.colorado.edu/sims/html/capacitor-lab-basics/latest/capacitor-lab-basics_en.html

Click 'Capacitance'. Keep all default settings. In the top left of the screen check the option **'Top Plate charge'**. This will display the charge on the top plate. Notice the default is zero since the battery is set to zero volts.

2) Click and drag to move the slider on the battery up till the charge on the top plate becomes $0.10\ pC$. On the top right of the screen, check the option 'Electric Field'. This displays the field lines of the electric field between the plates.
a) Count how many field lines are there.

b) Is the density of the field lines constant between the plates or are they more crowded at certain points?

c) What does this tell you about the intensity of the electric filed for all points between the parallel plates? Notice that the field lines are perpendicular to the parallel plates of the capacitor.

d) Can you expect how the equipotential surfaces would look like between the two plates?

e) Which equipotential surface between or at the two plates will have the highest electric potential? and

f) which will have the lowest electric potential?

3) Now change the slider on the battery so that the charge of the top plate is $0.30\ pC$. Notice the filed lines now.

a) Does the density of the field lines increase?

b) What does this tell you about the intensity of the electric field between the plates now?

4) Now move the slider on the battery to the lower part so that the charge on the top plate becomes $0.30\ pC$ (this time notice that this charge on the top plate is a $\boldsymbol{negative}$ charge, although the box at the top of the simulator does not write the negative, but it shows the negative on the capacitor itself).

a) What happened to the direction of the electric field now?

b) Which surface at or between the plates will have the largest electric potential and

c) which will have the lowest electric potential?

5) Watch this video https://www.youtube.com/watch?v=XSXKk_A3xUM

After you watch the video review your answer to step (2): b) and c) and to step (3): a) and b) above. Explain.

Part 3: A spherical conductor and oppositely charged conductor plates

1) Watch this video: https://www.youtube.com/watch?v=1XI4D4SgHTw then answer the following questions.

2) Which diagram (a, b or c) correctly represents the field lines for a neutral conductor sphere placed between two oppositely charged parallel plates? Explain why. (Hint: See 'Field lines' in the introduction).

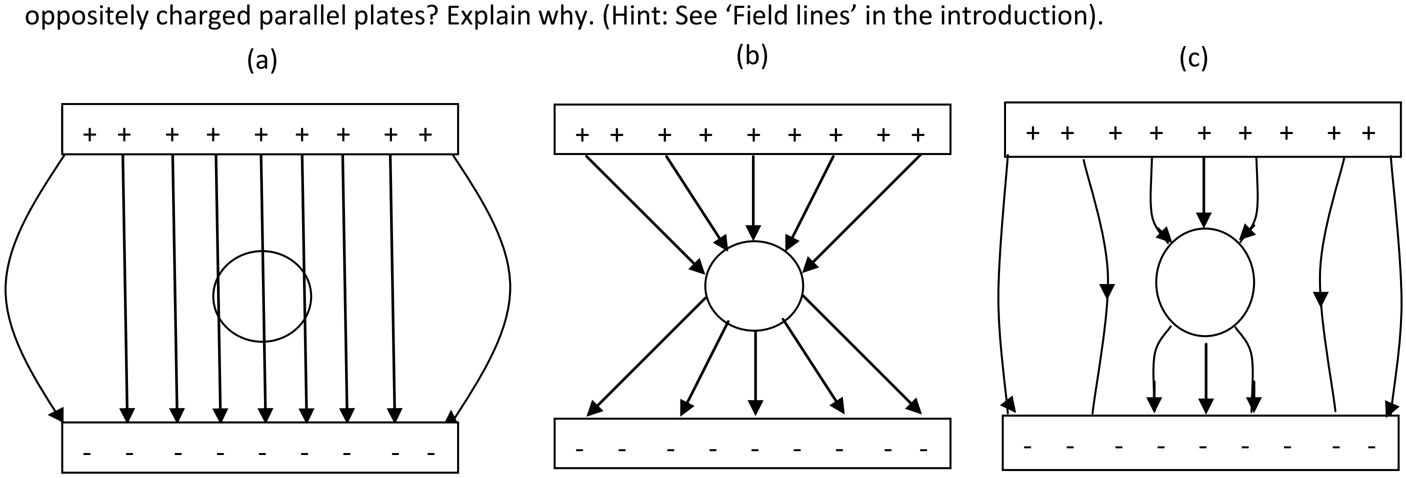


Figure 4: Multiple choice question for a neutral conductor sphere between oppositely charged parallel plates

Part 4: A circular conductor and one conductor plate that are oppositely charged

1) Examine the photo in fig. 5 below for a cylinder conductor and a plate oppositely charged. Threads were placed suspended in oil to map the electric field lines.

2) What do you notice about the electric field inside the cylinder?

3) What do you notice about the angle between the electric field line and each point on the surface of each conductor?

4) Some of the field lines for a conductor circle and a conductor rod that are oppositely charged are sketched in fig. 6 below.

According to your observation of the photo, and your answers to the questions in steps (2) and (3), answer the following about the few of the field lines that are sketched in fig. 6:

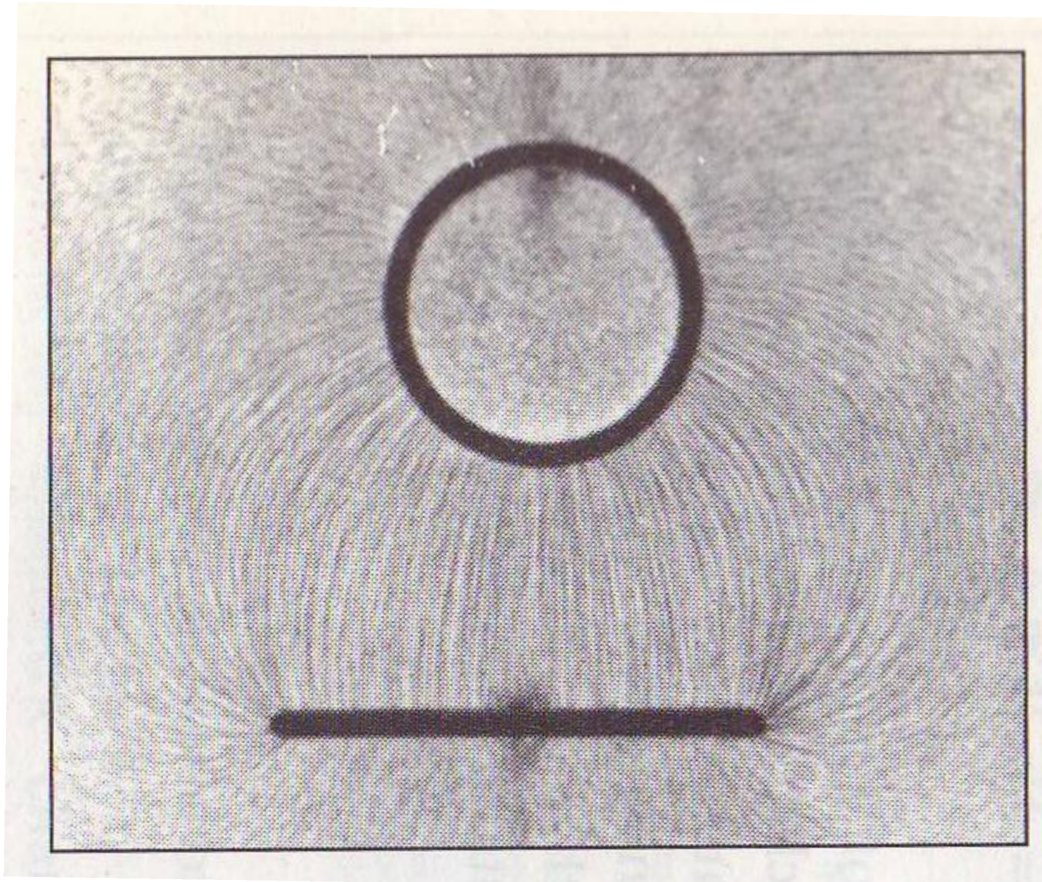


Figure 5: Photo of a cylinder and a plate, oppositely charged. *(*From Serway, *Physics for scientists and engineerss,* 4th edition, Ch. 24, Saunders College Publishing, 1995. Photo is *courtesy of Harold M. Waage, Princeton University)*

a) Are the field lines perpendicular to the points of the surfaces of the conductors?

b) Would the equipotential line between points A and B be horizontal and parallel to the rod? Why?

c) Will the equipotential between points C and D be a curve? Why?

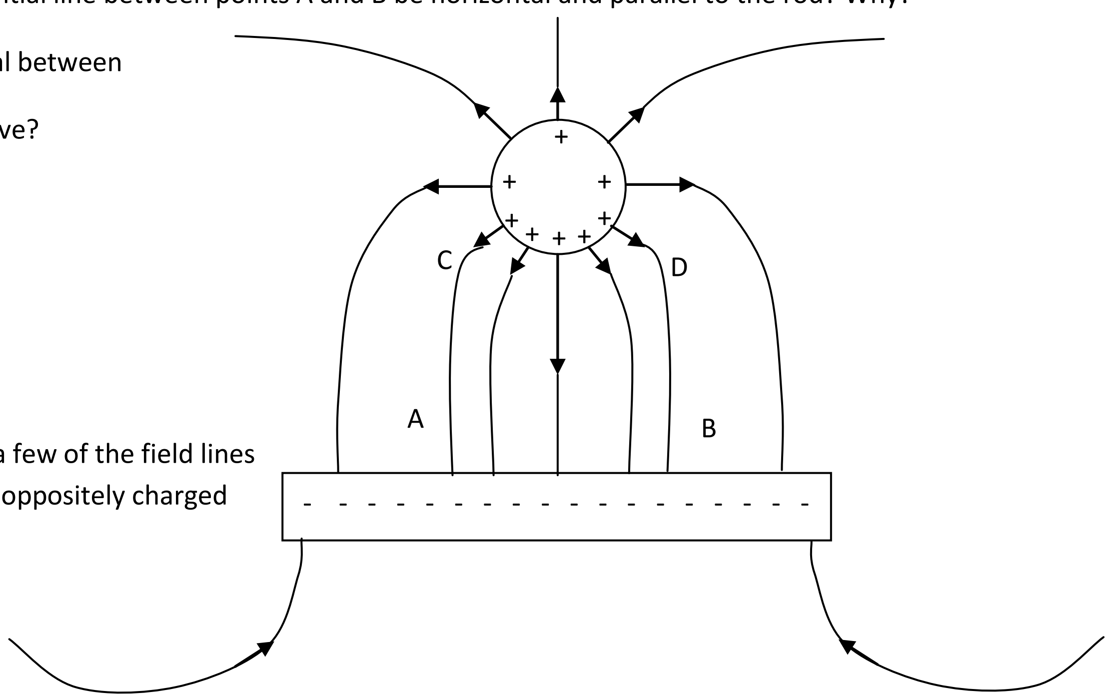


Figure 6: A sketch of a few of the field lines for a circle and a rod, oppositely charged

Data sheet

Name: **Group:** **Date experiment performed:**

<u>Introduction question</u>: Answer to question a) Why is the surface of a conductor always an equiporential surface?

Part 1: Equipotential surfaces for two oppositely charged point charges

Step 3) Do you expect the vertical line at $x = 0$ to be an equipotential?

Step 4) a) Step 4) b)

Step 5) Step 6) $(x, y) =$

Step 8) Table

	15 v	2.4 v	1 v	−1 v	−2.4 v	−6 v	−15 v
(x, y)							

Step 9) Submit your screen shot of the complete equipotential plot for the electric potential values above.

Part 2: Field lines for a parallel conductor plates (parallel plate capacitor)

Step 2)

a) How many field lines are there? b) Is the density of the field lines constant?

c) What does this tell you about the intensity of the electric filed for all points between the parallel plates?

d) Expectation of how the equipotential surfaces would look like:

e) Which equipotential surface will have the highest electric potential?

f) Which equipotential surface will have the lowest electric potential?

Step 3)

a) Does the density of the field lines increase?

b) What does this tell you about the intensity of the electric field between the plates now?

Step 4)

a) What happened to the direction of the electric field now?

b) Which surface at or between the plates will have the largest electric potential and

c) which will have the lowest electric potential?

Step 5)
After you watched the video, were your answers correct for step (2): b) and c) and for step (3): a) and b)? Explain.

(continue for parts 3 and 4 on the next page)

Part 3: A spherical conductor and oppositely charged conductor plates

Step 2) Which diagram (a, b or c) correctly represents the field lines?

Explain why?

Part 4: A circular conductor and one conductor plate that are oppositely charged

Step 2) For the photo in fig. 5, what do you notice about the electric field inside the cylinder?

Step 3) For the photo in fig. 5, what do you notice about the angle between the electric field line and each point on the surface of each conductor?

Step 4)

For fig. 6, a) Are the field lines perpendicular to the points of the surfaces of the conductors?

b) For fig. 6, would the equipotential line between points A and B be horizontal and parallel to the rod? Why?

c) For fig. 6, c) Will the equipotential between

points C and D be a curve?

Why?

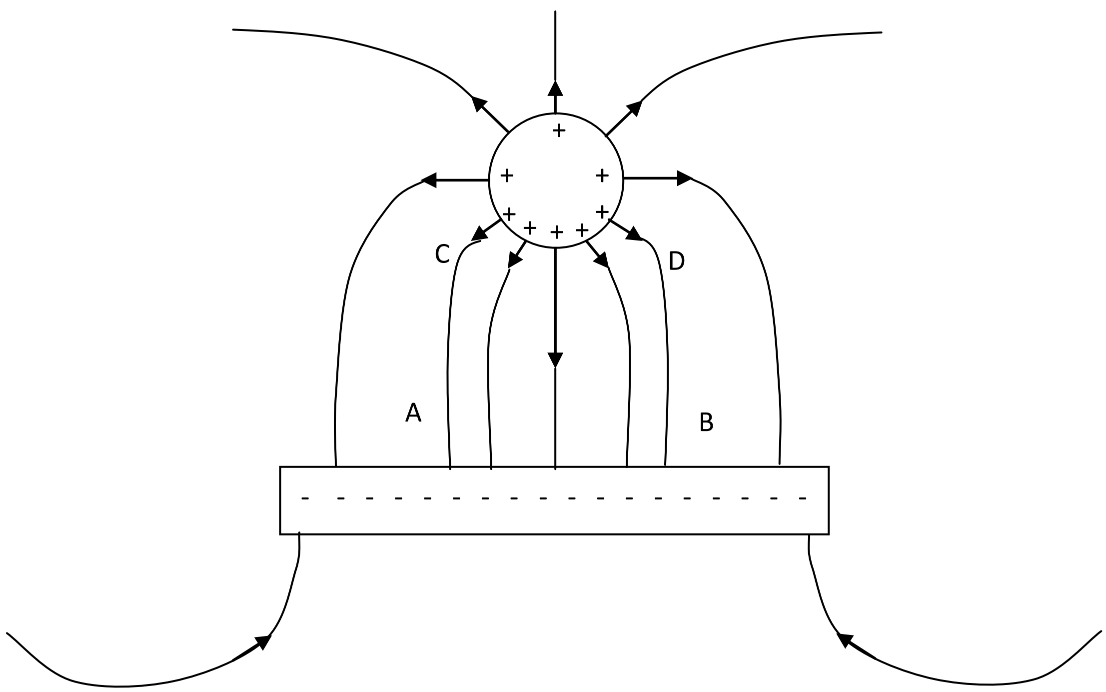


Figure 6: A sketch of a few of the field lines for a circle and a rod, oppositely charged