Charges and Fields (E2)

Objectives

- Understand how electric field pattern is formed by various charge configurations (single charge, dipole and a four-charge setup).
- Understand what equipotential lines signify.
- Use the computer simulation program to calculate potential and plot equipotential lines in two dimensions.

Theory

A. Electric Fields and Electric Field Lines

You have already learned that like charges repel and opposites attract, according to Coulomb's Law.

$$F = k_C \frac{q_1 * q_2}{r^2}$$

How do these particles "feel" the attractive or repulsive force without touching? The answer is that each of the particles creates an electric field, which influences nearby charges. Similar to the electrical force, the electric field has both magnitude and direction (it is called a **vector field**). The magnitude at any point is defined as the force per unit of charge. Therefore, if a charge q_2 experiences a force F at some point, then the value of the electric field E at that point is given by

$$E = \frac{F}{q_2}$$

We measure electric field E in (N/C). The magnitude of the electric field present at a distance r from a <u>point charge</u> q_1 is given by

$$E = \frac{F}{q_2} = k_C \frac{q_1}{r^2} \propto \frac{1}{r^2}$$

where k_C is a constant of proportionality and is equal to: $k_C = 9.0 * 10^9 \frac{N*m^2}{C^2}$.

The direction of the electric field (shown by vector arrows) is then defined to be the direction in which a small <u>positive</u> test charge would move if released. The direction of the force and electric field vectors at any point is the same.

B. Electric Potential and Equipotential Surfaces

Just as an object in a gravitational field may have a gravitational potential energy, a charged object can also have a potential energy because of its location in electric field. The potential energy of a charge q_2 at any point is defined as the work, W, done on the charge by an external force as that charge moves from infinity to the point in question.

Because the potential energy U merely depends on the final location of a test charge, it becomes apparent that the *difference* in potential energy of the test charge as it moves between any two points is <u>independent</u> of the path taken. We call this type of field a *conservative field*. Both electric and gravitational fields are conservative.

$$\Delta U = U_f - U_i$$

Because potential energy is difficult to measure, it is convenient to discuss, **electrical potential** V (measured in Volts). The electrical potential is simply defined as the potential energy per unit (positive) charge. The electric potential due to a **point charge q_1** is given by

$$V = E * r = k_C \frac{q_1}{r} = k_C q_1 \frac{1}{r} \propto \frac{1}{r}$$

where $k_C = 9.0*10^9 \frac{N*m^2}{C^2}$ (the same constant of proportionality as before), q_1 (C) is charge, and r (m) is distance. We measure the electric potential in Volts (V).

$$1V = \frac{J}{C} = \frac{Nm}{C}$$

All the points that have the same potential are located on a surface called an <u>equipotential surface</u>. Each surface corresponds to a different value of the potential. Because this potential remains constant, <u>no work is done by an electric field as a charge moves between any two points on the same equipotential surface</u>. In two-dimension images, the equipotential surfaces are replaced by **equipotential lines**.

C. Properties of Electric Field Vectors, Electric Field Lines and Equipotential Lines

1. Electric field lines start on positive charges and ends on negative charges.
2. Electric field lines are perpendicular to equipotential surface (perpendicular to equipotential line in two-dimensional drawing).
3. Electric field lines never cross.
4. The electric field vector is tangent to the electric field line.
5. The closer the equipotential lines are to each other, the stronger the electric field is in that region.

Procedure

In this experiment, you will use "Charges and Fields" computer simulation to examine electric field lines and equipotential surfaces for four <u>charge configurations</u>:

(1) point charge,

(2) two identical point charges

(3) two charges with the same value, but opposite sign (electric dipole)

(4) four charges - two positive and two negative charges (electric quadrupole).

We are going to measure both the electric field values and the electric potential as a function of distance. Later you will search for spots with zero electric field and/or zero electric potential. We will also use "Charges and Fields" simulation to plot equipotential lines.

Login using your Purdue career account. Enter your login name and password. Download files for experiment E2 from the Brightspace page for Physics 221 or Physics 252 lab activities folder. Save it to the desktop.

Setting up the simulation
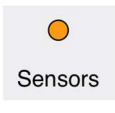
"PhET Interactive Simulations, University of Colorado Boulder, <u>https://phet.colorado.edu</u>."

The "Charges and Fields" simulation is a part of the collection of interactive simulations called PhET, which was developed at University of Colorado Boulder. To run the "Charges and Fields" simulation, download "*charges-and-fields_en*" file from the Brightspace page for Physics 221 or Physics 252 lab activities folder. Next, double-click on it to start the simulation. Save it to the desktop. Since this is an html document, it should start the default browser application.

"Charges and Fields" user interface is a very simple. The basic description of the interface is shown on the next page.

To measure distance, you need to activate the "Grid" option. The smallest grid unit represents distance equal to 0.10 m. The major grid lines are drawn every 0.50 m. **Select one intersection of major grid lines that is located at the center of the "Charges and Fields" window as the point with coordinates (x=0, y=0)** and <u>measure all distances from this point</u>. For example, in the second simulation, we will move two positive charges to locations (-1m, 0) and (1m, 0) on the screen.

To <u>measure the electric field</u> value E, you need to use the "Sensors" tool indicated by the small, orange circle [Sensors icon] . For <u>electric potential</u> value V, grab the measuring tool [0.0 V icon]

Once you move the tool, it changes to [Equipotential 2.678 V icon] . The measuring tool shows the value of the electric potential V at the point indicated by the cross hairs. To plot the equipotential line going through this point, click on the small pencil icon.

PhET   Charges and Fields

In **Charges and Fields** students explore electrostatics as they arrange positive and negative charges
space and observe the resulting electric field, voltage, and equipotential lines.

OBSERVE the
electric field

VIEW the
direction of the
electric field

DRAG charges
and sensors out
of the toolbox

MEASURE the
distance

MEASURE the
electric field at a
precise location

VIEW the electric
potential

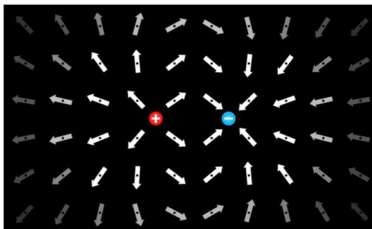**CHANGE** the
background color
of the sim to
white for
projection

PLOT
equipotential lines

Options…
PhET Website…
Report a Problem…
Check for Updates…
Screenshot
Full Screen
About…

Model Simplifications

- The charges are assumed to pinned wherever they are placed.

- The electric field is displayed using an array of arrows fixed to a grid. The brightness of the arrows indicates the magnitude of the field. This representation allows for discussion about the direction and magnitude of the electric field.

- The grid is arranged so that if a single charge is placed on a major intersection, the electric field will look like a classic textbook picture (left), whereas a charge placed off the grid may look odd (though still correct) at first glance (right).
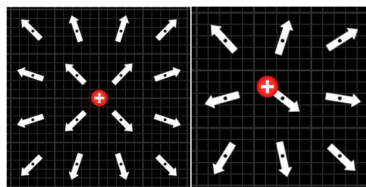
- The sensors can be used to detect the precise magnitude and direction of the E-field at any location.

- Charges can be placed on top of one other. If a +/- pair is overlapped, the electric field will become zero.

- The electric potential V at the infinity is assumed to be equal to zero, which is a typical arrangement. All potential values are shown in this simulation are relative to the zero potential at infinity.

After you start the "Charges and Fields simulation, please set the following **initial conditions**: "Values" and "Grid" should be checked. Electric Field", "Voltage" and "Direction only" should not be checked. From "Options" menu select "Projector Mode" and activate it. The "Charges and Fields" windows after the initial setup should look like this.
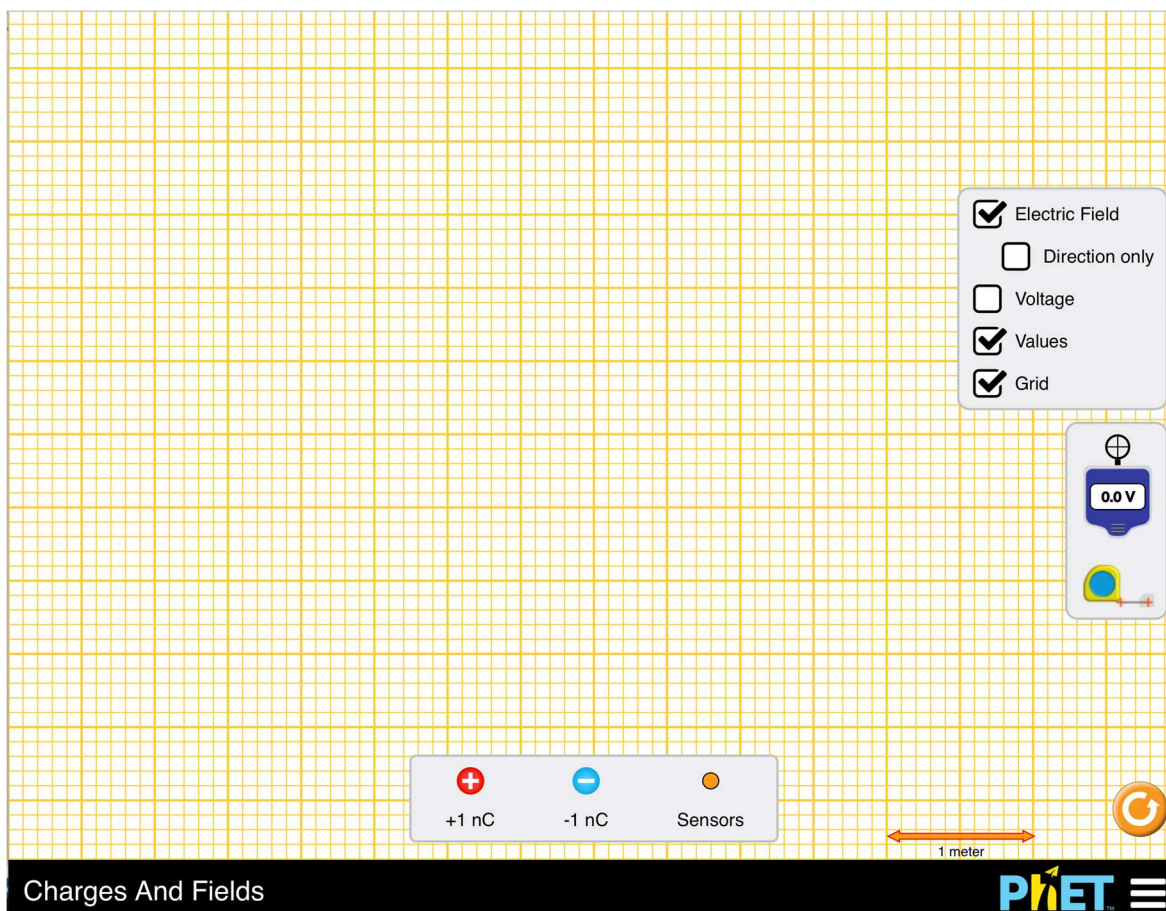
Now you should be ready to run simulations.

The step-by-step instructions for the simulations 1-3 are in the Data Sheets pages.

Make sure to complete the following tasks:

You must submit the answers to the prelaboratory questions online.   (3.5 points)

1. Two printed screen copies from Simulations 1 and 3.   (2×1p. =2 points)

   (Title and <u>write your name</u> and those of your partners on each graph.)

2. The *E* and *V* vs. *r* graph for a point charge (Simulation 1).   (1 point)

3. Your completed Data Sheets.   (3.5 points)

4. Return the completed lab report to your lab TA.