Physics 123 Lab 2: Electric Field

Physics 123: Electricity and Magnetism

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Introduction

In the previous lab, you saw that two charged objects interact with one another *at a distance,* in other words, even when they are not in direct physical contact. This observation presents something of a mystery: *how* do the objects "know about" each other across the intervening distance? Is there some mechanism through which they "communicate?" Historically, scientists were resistant to the idea that these interactions could occur without a mechanism. Many regarded as superstitious the notion that a material object could exert an effect at a place where it was not. To address this concern, ideas such as the ether were invented to provide a mechanism through which charged objects could interact.

Ultimately, the concept of *electric field* was developed. This abstract idea is at the core of modern physics, and is used to explain a wide range of phenomena, including the observation that two charges interact over a distance. In the field view, an electric charge can play the role of a "source object," and alter the space around it, creating a field. A second electric charge can play the role of a "probe object," responding to this altered space by experiencing a force.

In this lab, you will develop a step-by-step procedure to define and measure the electric field. You will practice applying the field concept in a number of specific situations. You will use a computer simulation to conduct your work, making predictions and then using the simulator to "check" these predictions. During the lab, discuss your ideas with your partners and try to reach agreement. Write down your reasoning in enough detail for you to recreate your thinking later when doing the homework or studying for exams.

Learning Targets

After completing this lab, you should be able to**:**

1. Provide an *interpretation* of the electric field strength and the field direction.
2. Describe a procedure for measuring the electric field.
3. Determine the force exerted on a point charge in a given electric field.
4. Apply Coulomb's law to determine the field produced by a point charge.
5. Apply the Principle of Superposition to determine the field produced by multiple charges.

Equipment:

- One red and four blue balls (for instructor-led demonstration at beginning of lab)
- Access to computer with internet connection

Activity I: The concept of electric field

This activity focuses on Learning Targets 1 and 2. Your instructor will lead a full-class discussion. Once the discussion is complete, collaborate with your partners to answer the summarizing questions below.

A. The electric field is a vector quantity, and thus has both direction and magnitude.

   1. Describe in your own words the significance of the *direction of the electric field.* What specific information does this direction provide?

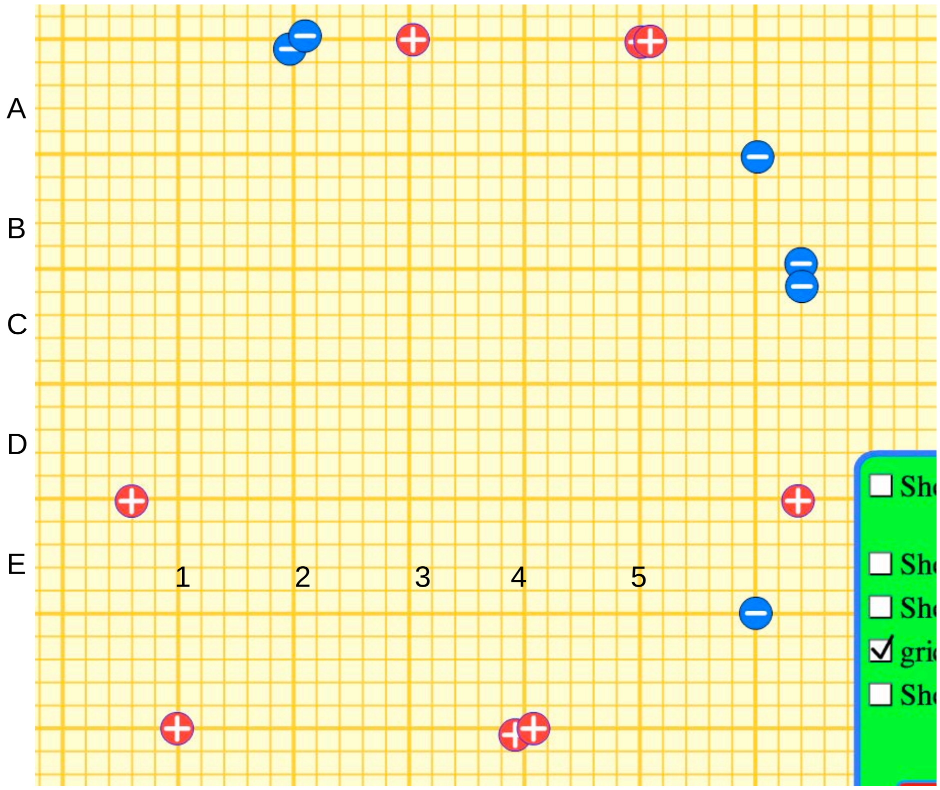
   2. Describe in your own words the significance of the *magnitude of the electric field* (also referred to as *electric field strength).* What specific information does this quantity provide?

B. Suppose an unknown distribution of source charges is arranged in space. You want to find the electric field that is produced. Formulate a series of steps that could be taken to experimentally determine the magnitude and direction of the electric field at some point *P*. How would a probe charge be used?

C. Explain in your own words why the value of the electric field is *independent* of the probe charge that is used to measure it. (What does "independent" mean in this context?)

Activity II: Relating electric field and electric force

This activity focuses on Learning Targets 1 and 3. Start the program **Charges and Fields.** (Ask your instructor if you are not sure how to do this.) Once it is running, select the "grid" and "show numbers" checkboxes, but leave the remaining checkboxes unselected. Drag charges onto the grid to reproduce the configuration shown below.



The grid lines in the screenshot above have been labeled A-E and 1-5 so that locations on the grid can be referred to.

The point charges that you have put in place are referred to as *source charges.* These sources create an electrical "influence" in the central region. The computer program allows you to explore this influence. When doing so, you can consider the source charges to be "hidden off-stage". In other words, you will make measurements of the electric influence produced by the sources without paying direct attention to the sources themselves, almost as if the source charge distribution were unknown.

A. Drag an E-field sensor to location C3 and release it. You should see a vector. Now grab the sensor and drag it around the screen. The vector should change direction and magnitude.
   1. Give an interpretation of the vector's *direction*. What information does it convey? *(Note:* "Direction of the E-field" is a name, but *not* an interpretation. If you are not sure how to answer this question, refer back to your group's consensus answers from Activity I.)

Now place the sensor back at C3. If the "show numbers" checkbox is selected, you should see a numerical readout of the magnitude of the vector. *(Note:* The simulation readout employs units of "V/m", or volts per meter. This unit is equivalent to Newtons per Coulomb; *i.e.*, 1 V/m = 1 N/C.)

2. Give an interpretation of the magnitude of the electric field vector. What specific information does the magnitude convey about this situation? (*Hint:* Use the unit "Newtons per Coulomb" to guide your thinking.)

B. Place sensors at grid points B2-D4 to form a 3x3 array. You can think of the resulting set of vectors as a "map" of the electric field in this region of space.
1. Suppose a +5 Coulomb probe charge were placed at grid point B3. Approximately how many units of force would it experience? Explain.

2. Where could you place a –2 Coulomb probe charge so that it would experience a force of about 3 Newtons? Explain.

3. If you were to release a –1 Coulomb probe charge from rest at grid point D4, in what direction would it start to move? Explain.

C. Select one of the grid points. The electric field strength, displayed by the sensor, tells the amount of force that would be exerted on a one-unit probe charge if it were placed at that grid point.
1. How many Coulombs of probe charge would you need to place at the grid point in order for that probe charge to experience 1 Newton of force? Explain.

2. Consider a new, "made up" concept: the *Unit-Force Charge.* (Let's call it the "Unifarge".) The magnitude of the Unifarge is the number of Coulombs of probe charge that experiences 1 Newton of force. Review your steps from I.B for experimentally determining the electric field. Below, modify those steps to create a procedure for measuring the Unifarge.

Activity III: The electric field produced by a point charge

In the view of electrical interactions that you have been studying, source charges create a field, which in turn interacts with a probe charge:

Source Charges $\Rightarrow$ *Field* $\Rightarrow$ *Probe charge*

In Activities I and II, you devised a method for measuring the electric field and related the field to the force exerted on a probe charge. This activity begins to examine the issue of how source charges *produce* electric fields. The basis for this analysis is *Coulomb's law*, which can be used to find the electric field produced by the simplest possible source distribution: a single point charge.

As you may have seen previously in the course, measurements of the force exerted on one point charge by another suggest that the magnitude of the electric field produced at some location P by a point charge q is:

- proportional to q, and
- inversely proportional to the square of the distance between the point charge and location P.

These findings are part of *Coulomb's law.*

The following activities are designed to build understanding of Learning Target 4.

A. Clear the screen of the source charges from the previous activity. Then complete the following:
Play with the simulator to verify that it does, in fact, obey the two bulleted rules presented above. Use the space below to describe the evidence you collect.

Note that each red or blue circle represents a charge of $\pm 10^{-9}$ Coulomb and that each small grid square represents a distance of 0.1 meters. Determine the value of the Coulomb's law constant that this computer simulation uses. Describe the measurements you make and how you come to your conclusion. Does the simulator value match the real world value?

B. Applications of Coulomb's law

- What happens to the electric field at a fixed distance away from a point source charge if that source charge is doubled? Justify your answer.

- How does the electric field a certain distance away from a source charge compare to the electric field at half that distance? Justify your answer.

- When a source charge is doubled, how must the distance from the source be changed in order to maintain the same electric field strength? Justify your answer.

Activity IV: Superposition

Coulomb's law provides only part of the story of how source charges create electric field. A remaining issue concerns what happens when there are multiple source charges.

Below you are asked to make predictions and check them with the simulator. Discuss each prediction with your partners and try to reach agreement. Then use the simulator. When you and your partners are confident that you can account for the results of the simulator experiment, explain your ideas in writing.

A. Return to the computer program **Charges and Fields**. Clear the screen, turn on the grid, and select "show numbers." Drag a single +1-unit source charge onto a grid point. Now place an E-Field Sensor at the location one large grid box (or 5 small boxes) to the right of the source charge. (We will call this location *P*.) Note the magnitude of the field at *P*.

   Suppose a second +1-unit source charged were placed on top of the first. What will be the magnitude and direction of the electric field at point *P*?

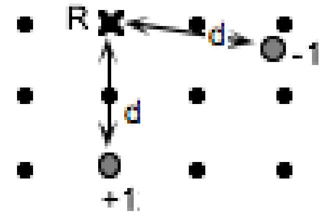
   - Initial prediction:
   - Observation and consensus explanation:

B. Let's refer to the two source charges as A and B. Suppose that charge B were dragged one large grid box to the left of charge A. What will be the magnitude of the electric field vector at point *P*?

   - Initial prediction (Try to do this without a calculator! Use proportional reasoning and round to the nearest whole number.):
   - Observation and consensus explanation:

Your results thus far suggest that when multiple source charges are present, the net electric field is the sum of the fields produced by each charge. In other words, each point charge contributes to the field *as if it alone were present.* This property of electric fields is referred to as the *principle of superposition.*

C. Consider the situation at right, in which a +1-unit and a –1-unit charge are equidistant from point R as shown. If the –1-unit charge were removed, would the magnitude of the electric field at point R *increase, decrease,* or *remain unchanged?*



- Initial prediction:
- Observation and consensus explanation (make sure to draw a head-to-tail vector addition diagram to illustrate your ideas, if you have not done so already):

Activity V: Reflection

Obtain your prelab. Compare your answers and explanations with those of your partners. Note any differences and try to come to agreement. Note that you have already discussed ideas about Question 1 on the prelab (part C above). If you feel stuck on Question 2, check out the hints in the box below.

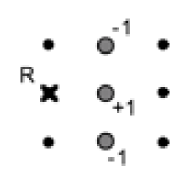
Hints for Prelab Question 2
Try to answer this question without a detailed calculation. Instead, use proportional reasoning and ideas about vector addition. The questions below can be useful as intermediate steps.
- Draw a vector diagram to show the contribution that each source charge makes to the electric field at point R.
- How does the magnitude of the contribution of one of the –1 charges compare to that of the +1 charge? Is it half as great? one-quarter as great? a factor 1/Sqrt(2) as great?
- Think about adding your three vectors together to the get the net electric field at point R. What does your answer about the magnitudes (previous question) imply about the result?

Once you have agreed with your partners on the explanations for the prelab questions, reflect on how your understanding has changed. Are there any aspects of your prelab responses that you now feel should be modified? Use colored pencils to annotate your prelab. Use green or blue to mark the parts of your reasoning that were productive, and red to mark parts that you now feel are problematic and need revising. Add brief comments to identify where and how your initial ideas were incorrect or incomplete. Focus not just on whether you had the correct answers, but also on the quality of your explanations. Discuss your reflections with your partners.

When you are ready, discuss your annotated prelab with your instructor.

Activity VI: Synthesis challenge

Consider the physical situation from the prelab (shown at right). You have verified using the simulator that the electric field at point R is to the left. There is some location on the x-axis, call it point *P*, at which the electric field is zero. Your task is to determine, using a theory-based calculation, the location of point *P*.



When you have your prediction, call your instructor over. Then use the simulator to check your results. Make notes in the space below so that later, when doing the mini-report for your lab HW, you can recall your group's thinking.