LABORATORY II
ELECTRIC FIELDS AND ELECTRIC POTENTIALS

In this lab you will continue to investigate the abstract concept of electric field. If you know the electric field at a point in space, you can easily determine the force exerted on a charged object placed at that point. The concept of field has the practical advantage that you can determine the forces on an object in two stages. To determine the force exerted on object A by other objects, you first determine the field, at a location to be occupied by A, *due to all objects except for object A.* You then calculate the force exerted on object A by that field. That force depends only on *the properties of object A* and *the value of the field* at object A's location. An advantage of this two-step approach is that if you make no changes but replace object A with a new object, B, it is simple to calculate the force exerted on object B. This is because replacing A with B does not change the field. *The field that exerts a force on an object depends only on the other objects.*

Keeping track of forces and accelerations is not always the simplest approach for predicting the behavior of objects. It is often more convenient to use the principle of Conservation of Energy. As mentioned in the introduction to the previous lab, the potential energy related to the position of a charged object resides in the surrounding field. As with forces on an object (A) due to a field, the change in potential energy due to the addition of an object (A) to a configuration of other objects is calculated in two stages. First you calculate the "potential," at a location to be occupied by object A, *due to all objects except for object A.* That potential depends only on the other objects and does not depend on any properties of object A. You then use the value of the potential at that location to calculate the change in potential energy when object A is placed there. That potential energy depends *only* on the properties of object A and the value of the potential at object A's location. As with forces, it would then be a simple matter to calculate the potential energy change due to replacing object A with another object B.

Because the concepts of field and potential are abstract and difficult to visualize, this laboratory uses a computer simulation based on the interaction of point charged objects (usually called point charges). With this simulation you can construct a complicated charge configuration and read out the resulting electric field and electric potential at any point in space.

OBJECTIVES

After successfully completing this laboratory, you should be able to:

- Qualitatively determine the electric field at a point in space caused by a configuration of charged objects based on the geometry of those objects.
- Calculate the electric field at a point in space caused by a configuration of charged objects based on the geometry of those objects.
- Qualitatively determine the electric potential at a point in space caused by a configuration of charged objects based on the geometry of those objects.
- Calculate the electric potential at a point in space caused by a configuration of charged objects based on the geometry of those objects.
- Relate the electric field caused by charged objects to the electric potential caused by charged objects.

PREPARATION

Read: Fishbane Chapters 22, 24.

Before coming to lab you should be able to:

- Add vectors in two dimensions.
- Calculate the electric field due to a point charge.
- Calculate the electric potential due to a point charge.
- Use the computer simulation program, EM Field.

SIMULATION PROBLEM #1
THE ELECTRIC FIELD FROM MULTIPLE POINT CHARGES

You work with a biochemical engineering group investigating new insulin-fabrication techniques. Part of your task is to calculate electric fields produced by complex molecules. The team has decided to use a computer simulation to calculate the fields. Your task is to determine if the simulation agrees with the physics that you know. You decide to determine the electric field at a point from a set of charged objects that is complex enough to test the simulation but simple enough to make direct calculation possible. The first configuration you try is a square with two equal negatively charged point objects in opposite corners and a positively charged point object of 1/3 the magnitude of the negative charges in a third corner. You will calculate the electric field at the remaining corner of the square and compare your result to that of the computer simulation of the same configuration.

EQUIPMENT

The computer program EM Field and a ruler.

PREDICTION

Restate the problem. What do you need to calculate? How do you calculate a total electric field from a collection of point charges?

WARM-UP QUESTIONS

Read: Fishbane Chapter 22. Read carefully Sections 22-1 and 22-2 and Examples 22-3 and 22-4.

1. Make a picture of the situation. Label the objects and their charges. At the point of interest, draw and label an electric field vector caused by each of the charged objects.

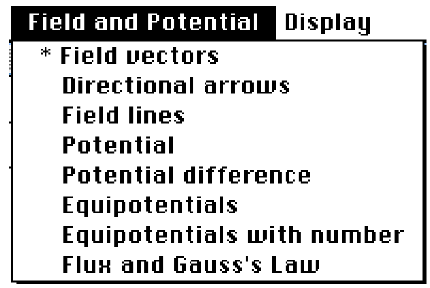
2. Determine the magnitude and direction of each of the three electric field vectors at the point of interest in terms of the charge magnitudes and the length of the square's sides. You may need geometry and trigonometry to determine distances.

3. Choose a useful coordinate system. Draw each electric field vector on your coordinate system. Write an expression for each component of each vector.

4. Find the components of the total electric field vector at the point of interest, and then use them to write an expression for both the magnitude and direction of the electric field at the point of interest. Remember what you have learned about adding vectors.

EXPLORATION

On the desktop, open <u>EM Field</u> and click anywhere in the window for the instructions. From the *Sources* pull-down menu, select *3D point charges*. Drag any positive charge to the center of the window of <u>EM Field</u>. From the *Field and Potential* pull-down menu (shown to the right), select *Field vectors.*



You can reveal electric field vectors using the left button on the mouse: drag the cursor to scan and release the button at the locations where you would like the electric field to remain displayed. Look at the *Display* drop-down menu and explore its options. To place objects at precise points on the screen you can use the *show grid* and *constrain to grid* features from the *display* pull-down menu. Expand the display window to fill the entire computer screen.

Measure the length of the electric field vector at several locations, as well as the distance from the locations to the center of the charged point object. You can remove the displayed vectors using the C*lean up screen* option from the *Display* drop-down menu.

Try using different magnitudes of charge. What range of charge values allows you to accurately measure the length of the electric field vector at all points on the screen?

To check whether or not you get the correct behavior of the electric field from a point charge do the following:

1. Pick several locations at different distances *r* from the center of the single point charge. For each of the locations, measure *r* and the length of the electric field vector.

2. Draw what the Coulomb's law predicts for the field strength vs. distance (*r*) graph.

3. Plot the measured electric field vector lengths as a function of the distance to the center of the charged point object. Compare the shape of the graph to that based on the Coulombs' law.

You have to calibrate the computer simulation program to be able to translate the lengths of electric field vectors into magnitudes of the electric field represented. Using a charged point object whose electric field can be determined, you can do this in the following way.

1. Pick a distance *r*, for which you have measured the electric field vector length. Assume charges are given in Coulombs by the simulation program. Use Coulomb's law to *calculate in SI units* the magnitude of the electric field produced by the point charge at that distance.

2. Find the ratio of the calculated electric field magnitude to the vector length.

3. Repeat this for several other distances. Estimate the percentage within which you can claim that you get the same ratio for different distances. If the uncertainty is reasonably low, calculate the average value of the ratio. This number can now be used as a conversion factor to translate measured lengths of the electric field vector into electric field strengths.

Verify qualitatively that the simulation gives the correct behavior of the electric field from a pair of point charges. Try opposite charges of the same absolute value first. Where does the field go to zero? Does this behavior match what is expected? Repeat this qualitative analysis for two identical charges.

Let us explore a distribution of three charges. Drag two negative charges and one positive charge onto the screen. Look at the electric field vectors at various points around the charge distribution. Try changing the magnitudes of the charges, the signs of the charges, the distances between them, and their locations on the screen.

To reproduce the configuration under study in this problem, place two negative charges in opposite corners of a square using *constrain to grid*. (Larger charges are recommended; besides, keep in mind that you will be adding a positive charge of 1/3 the magnitude.) Add the positive charge. Explore the electric field at different locations. Note the length of the electric field vector in the forth corner of the square. What parameter can you vary to change the length of the electric field vector at that point preserving the conditions of the problem? If needed, move the charges to make the electric field vector length in the forth corner of the square large enough for accurate measurement. In your journal, note whether or not such manipulations change the direction of the electric field at that corner, and record the direction.

MEASUREMENT

Measure the length of the electric field vector at the point of interest.

ANALYSIS

Use the data that you have collected for thew following analysis.

1. Convert the length of the electric field vector produced by the computer simulation into electric field strength.

2. Using the Coulomb’s law, calculate electric fields at the measurement location from each of the three charges.

3. Introduce a two-dimensional coordinate system and calculate two components for each of the three fields. When estimating components of a vector, you should always take into account its direction.

4. Add x-components (with their correct signs) of three fields to get the x-component of the electric field in the forth corner due to all three charges. Similarly, add y-components.

5. Use the calculated components of the (total) electric field in the forth corner to find its magnitude.

6. Compare your calculated electric field strength to that from the computer simulation. Also compare your prediction for the direction of the field to that from the computer simulation.

CONCLUSIONS

Did the result of your calculations using the Coulomb's law match the value obtained by converting the length of the electric field vector from the computer simulation? Explain any differences.

What properties of electric field due to one or more point charges can be seen from and / or supported by the computer simulation? Use evidence from both the exploration and measurement parts of the experiment to formulate your answer.

SIMULATION PROBLEM #2
THE ELECTRIC FIELD FROM A LINE OF CHARGE

You are a member of a team designing an electrostatic air cleaner for the use of people suffering from allergies. The air passage through the device will contain many complicated charged electrodes. You must determine the effect of these electrodes on plant spores that cause allergic reactions. The first step is to calculate the electric field at every point in the air passage. Because the electrode configuration is complicated, your team has decided to use a computer simulation to model the resulting electric field. Your task is to determine if the simulation results agree with the physics you know for non-point-like charged objects. You decide to test the simulation for the case of a uniformly charged rod, since this situation is simple enough for you to calculate. For comparison with the simulation results, you decide to calculate the electric field at a point a short distance from the middle of the rod along a line perpendicular to it, and also at a point a short distance from the end of the rod along its axis.

EQUIPMENT

The computer program EM Field and a ruler.

PREDICTION

Restate the problem. What do you need to calculate? How do you calculate the total electric field due to a continuous charge distribution?

WARM-UP QUESTIONS

Read: Fishbane Sections 22-1, 22-2, and 22-3.

1. Make a picture of the situation. Select one of the points of interest. Label any relevant constant quantities. Label all relevant distances and angles. Decide on an appropriate coordinate system. Draw a charge element dq somewhere along the rod.

2. At the point of interest draw a vector d**E** representing the electric field produced by the element dq. Write an expression for its magnitude. Draw and label its components. Write an expression for the magnitude of each component.

3. For any charge distribution, the total electric field is found by calculating the contribution from each charge element to the total (vector) field, and summing the contributions (as vectors). When the charge distribution is continuous, it may be mathematically divided into infinitesimal elements dq; then (for each field component) the individual contributions are added together with an integral. Write an integral for *each component of* the total field at the point of interest in terms of the charge elements dq. (Note: Always consider the symmetry of the situation. It may be that the integral for one of the components does not need to be calculated.)

4. In order to evaluate an integral, all terms in the integrand must be either constant, or be explicit functions of the integration variable. The integral(s) from the previous step are conceptually straightforward but cannot be evaluated directly; the integrand(s), including dq, must be re-written in terms of a different integration variable. What is an appropriate integration variable in this case? Determine appropriate limits for the new integration variable. Use the Pythagorean Theorem, trigonometry, and the linear charge density to write your integrand(s) in a suitable form.

5. Evaluate the integral(s) to get an expression for the total electric field's components at the point of interest. Write an expression for the total field magnitude and indicate its direction.

6. Repeat steps 1-5 for the other point of interest.

EXPLORATION

On the desktop, open the EM Field program. If you have done Problem #1, you are already familiar with this simulation software and it may be enough to just review the notes in your lab journal. Otherwise (or if you need to refresh or reinforce your knowledge of the EM Field simulation program) perform (repeat) the exploration from Problem #1. Two important goals of the Exploration part are (i) to check that the simulation software describes the electric field form a point charge correctly and (ii) to determine a conversion factor, which will be used to translate the measured lengths electric field vectors into absolute values of the vectors, i.e. into magnitudes of electric fields.

Let us now explore the configuration of charges to be studied in this experiment. From the *sources* pull-down menu select *3D Point Charges*. Drag positive charges onto the screen to create a long, uniform line of charge.

Use the mouse (click or drag) to investigate how the magnitude and direction of the electric field depends on position. Display electric field vectors by clicking at the locations of interest for this problem. To obtain electric field vectors of accurately measurable lengths at the locations of interest, you may have to adjust the number of charges and their magnitudes (use *Add more charges* from the *Sources* pull-down menu).

MEASUREMENT

Place charges on the screen to simulate the situation described in the problem. Measure the length and direction of the electric field vector, as well as any other quantities necessary for your prediction equation, at the points of interest.

ANALYSIS

Translate the length of the electric field vectors produced by the computer simulation into electric field strengths. For the situation in the problem, compare your calculated electric field strengths to those from the computer simulation. Also compare your prediction for the direction of the fields to those from the computer simulation.

CONCLUSION

Did your results match your predictions? Explain any differences. What physical principles are consistent with the computer simulation? Use evidence from the exploration and measurement to support your answer.

SIMULATION PROBLEM #3
ELECTRIC POTENTIAL FROM MULTIPLE POINT CHARGES

You are a member of a team building the world's highest intensity particle accelerator. In this machine, charged atomic nuclei are brought from a very slow speed to almost the speed of light by passing them through a charged electrode structure. You need to determine the effect of these electrodes on the speed of various nuclei. The first step is to calculate the electric potential that affects the nuclei. Because the charged electrode configuration is so complicated, your team has decided to use a computer simulation. Your task is to determine if the simulation results agree with the physics that you know. You decide to calculate the electric potential at a point caused by a set of charged objects that is complex enough to test the simulation but simple enough to make your calculation possible. The first configuration that you try is a square with two equal negatively charged point objects in opposite corners and a positively charged point object of 1/3 the magnitude of the negative charges in a third corner. You will calculate the electric potential at the remaining corner of the square and compare your result to that of the computer simulation of the same configuration.

EQUIPMENT

The computer program EM Field and a ruler.

PREDICTION

Restate the problem. What are you trying to calculate in your prediction? How do you calculate a total electric potential from a collection of point charges?

WARM-UP QUESTIONS

1. Draw a schematic of the charge configuration. Label the objects and their charges. Show and label all relevant distances and angles.

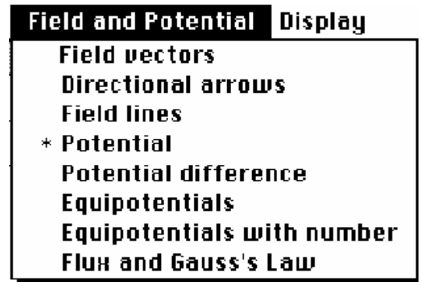
2. Write down equations for the (scalar) electric potentials at the point of interest caused by each of the three charged objects using the value of each charge and the size of the square. Use geometry to determine relevant distances.

3. Get the total electric potential at the point of interest by adding the electric potentials from step 2. Remember that even though it looks like we simply add up three quantities, the charges are of different signs and so are the potentials in the sum.

EXPLORATION

From the desktop, open EM Field and click anywhere in the window for the instructions.

From the *Sources* pull-down menu, select *3D point charges*. Drag any positive charge to the center of the window of EM Field. From the *Field and Potential* pull-down menu (as shown to the right), select *Potential.* Move the cursor where you would like to determine the electric potential and click the mouse button.



To place objects at precise points on the screen you can use the *show grid* and *constrain to grid* features of the program (from the *display* pull-down menu). It might also be helpful to expand the display window to fill the entire computer screen. You can do this by clicking on the small box in the upper right-hand corner of the display screen.

Another useful way to view electric potential involves equipotential surfaces. Select *Equipotentials with number* from the *Field and Potential* pull-down menu. Move the cursor where you would like to determine the electric potential and click the mouse button. How is this different from the *Potential* setting?

Try different magnitudes of charge. What range of charge values allows you to accurately measure the electric potential at a large number of locations on the screen?

Try using negative charges. How does this change the electric potential?

Check to see if you get the correct behavior of the electric potential from a point charge:

- Predict the shape of a graph of potential vs. distance (*r*). Graph the electric potential vs. the distance from the center of the charged point object. Is it the shape you expected?
- Predict the shape of a graph of potential vs. inverse distance (1/r). Graph the electric potential vs. (1/r). Is it the shape you expected?

You will need to translate the number the computer gives for the electric potential to appropriate units. Calibrate the computer simulation program using a charged point object whose actual electric potential can easily be determined:

- For one of the distances you used in the data that you took, calculate what the electric potential should be using Coulomb's law (assuming the value of the charge is in Coulombs).
- How does this compare to the number produced by the computer simulation program? Find the ratio between the calculated electric potential and the number produced by the simulation. How can you use this number to translate the computer simulation results into electric potentials?
- Repeat this for another distance to verify that you get the same ratio.

Qualitatively check to see if the program combines the electric potentials from two charged point objects correctly. Look at the cases of (a) equal and opposite charges and (b) two identical charges. Does the potential behave as you predict in each case? Does it go to zero where you predict it should in each case?

MEASUREMENT

Place charges on the screen to simulate the situation of interest. Measure the electric potential at the point of interest.

ANALYSIS

For the situation in the problem, compare your calculated electric potential to that from the computer simulation.

CONCLUSION

Did your results match your predictions? Explain any differences. What physical principles are consistent with the computer simulation? Use evidence from the exploration and measurement to support your answer.

SIMULATION PROBLEM #4
ELECTRIC POTENTIAL FROM A LINE OF CHARGE

You work with an astrophysics research group investigating the origin of high-energy particles in the galaxy. The group has just discovered a large electrically charged nebula with an irregular shape. In order to understand how this nebula affects the motion of charged particles passing nearby you must find the electric potential near the nebula. Because of its complicated shape you plan to use a computer simulation. You must determine if the simulation results match the physics you know. You decide to test the simulation for the case of a uniformly charged rod, since the situation is simple enough for direct calculation. You decide to calculate the electric potential at a point a short distance from the middle of the rod along a line perpendicular to it, and also at a point a short distance from the end of the rod along its axis. You will then compare these results with those obtained using the computer simulation, to see if the simulation can be trusted.

EQUIPMENT

The computer program EM Field and a ruler.

PREDICTION

Restate the problem. What do you need to calculate? How do you calculate the electric potential due to a continuous distribution of charge?

WARM-UP QUESTIONS

Read: Fishbane Chapter 24. Pay particular attention to Sections 24-2 and 24-5 and Examples 24-9, 24-10 and 24-11.

1. Make a picture of the situation. Select one of the points of interest. Label relevant distances, angles, and constant quantities. Decide on an appropriate coordinate system. Draw a charge element dq somewhere along the rod.

2. Write an expression for the (scalar) electric potential dV at the point of interest that is caused by your small element of charge dq.

3. For any charge distribution, the total electric potential is found by calculating the contribution from each charge element to the potential, and summing the contributions. When the charge distribution is continuous, it may be mathematically divided into infinitesimal elements dq; then the individual contributions are added together with an integral. Write an integral for the total potential at the point of interest in terms of the charge elements dq.

4. In order to evaluate an integral, all terms in the integrand must be either constant, or be explicit functions of the integration variable. The integral from the previous step is conceptually straightforward but cannot be evaluated directly; the integrand, including dq, must be re-written in terms of a different integration variable. What is an appropriate integration variable in this case? Determine appropriate limits for the new integration variable. Use the Pythagorean Theorem and the linear charge density to write your integrand in a suitable form.

5. Evaluate the integral to get an expression for the total electric potential at the point of interest. Repeat steps 1-5 for the other point of interest.

EXPLORATION

On the desktop open EM Field. If you have done Problem #3, review the notes in your journal. If you did not or your notes are incomplete, perform the exploration from Problem #3. The exploration from Problem #3 provides a technique for translating the values for potential produced by the simulation to actual potentials expressed in appropriate units.

From the *sources* pull-down menu select *3D Point Charges*. Drag positive charges onto the screen to create a long, uniform line of charge. Use the mouse to investigate how the electric potential depends on position. What number and magnitude of charges work best to give you electric potentials that can be accurately measured at the points of interest?

MEASUREMENT

Place charges on the screen to simulate the situation described in the problem. Measure the electric potential, as well as any other quantities necessary for your prediction equation, for the object at the points of interest.

ANALYSIS

Translate the values for potential produced by the simulation into actual potentials. For the situation in the problem, compare your calculated electric potential to that from the computer simulation.

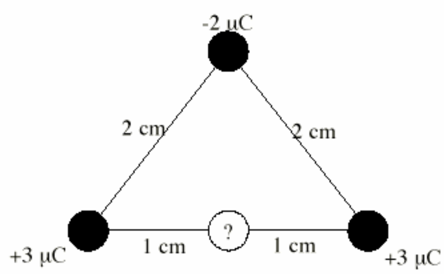
CONCLUSION

Did the computer simulation match your predictions? Explain any differences. What physical principles are consistent with the computer simulation? Use evidence from the exploration and measurement to support your answer.

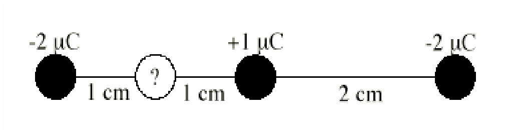
Where is the electric potential defined to be zero? Is this consistent with your results? If you completed problem 2 in this laboratory, do the following. For the point along the axis of the line of charge, take the derivative (with respect to distance from the rod) of the expression the potential. How does this compare with the magnitude of the electric field at this point that you calculated in the warm-up questions of Problem 2? How should it compare, and why?

☑ CHECK YOUR UNDERSTANDING

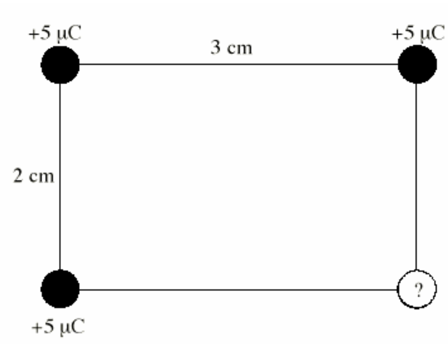
For each of the charge configurations below, find the electric field and the electric potential at the point marked with the "?".



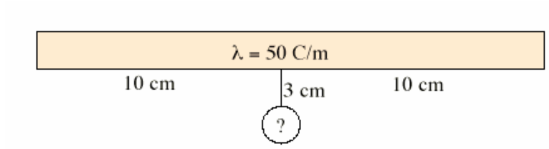
Configuration 1



Configuration 2



Configuration 3



Configuration 4

TA Name:____________________________

PHYSICS 1302 LABORATORY REPORT

Laboratory II

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ____________________________

Lab Partners' Names: ____

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Problem # and Title: ____

Lab Instructor's Initials: __________

Grading Checklist	Points*
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up questions completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL(incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
BONUS POINTS FOR TEAMWORK (as specified by course policy)	

* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.