LABORATORY I
ELECTRIC FIELDS AND FORCES

The most fundamental forces are characterized as "action-at-a-distance". This means that an object can exert a force on another object that is not in contact with it. You have already learned about the gravitational force, which is of this type. You are now learning the electric force, which is another one. Action-at-a-distance forces have two features that require some getting used to. First, it is hard to visualize objects interacting when they are not in contact. Second, if objects that interact by these action-at-a-distance forces are grouped into systems, the systems have potential energy. But where does the potential energy reside?

Inventing the concept of a field solves the conceptual difficulties of both the force and the potential energy for action-at-a-distance interactions. With a field theory, an object affects the space around it, creating a field. Another object entering this space is affected by that field and experiences a force. In this picture the two objects do not directly interact with each other: one object causes a field and the other object interacts directly with that field. The magnitude of the force on a particular object is the magnitude of the field (caused by all the other objects) at the particular object's position, multiplied by the property of that object that causes it to interact with that field. In the case of the gravitational force, that property is the mass of the object. (The magnitude of the gravitational field near the earth's surface is $g = 9.8\ \mathrm{m/s^2}$.) In the case of the electrical force, that property is the electric charge. The direction of the force on an object is determined by the direction of the field at the space the object occupies. When a system of two, or many, objects interact with each other through a field, the potential energy resides in the field.

Thinking of interactions in terms of fields is a very abstract way of thinking about the world. We accept the burden of this additional abstraction because it leads us to a deeper understanding of natural phenomena and inspires the invention of new applications. The problems in this laboratory are primarily designed to give you practice visualizing fields and using the field concept in solving problems.

In this laboratory, you will first explore electric fields by building different configurations of charged objects and mapping their electric fields. In the last two problems of, you will measure the behavior of electrons as they move through an electric field and compare this behavior to your calculations and your experience with gravitational fields.

OBJECTIVES

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

- Qualitatively construct the electric field caused by charged objects based on the geometry of those objects.
- Determine the magnitude and direction of the force on a charged particle in an electric field.

PREPARATION

Read Fishbane: Chapter 3, section 4; Chapter 22.

Before coming to lab you should be able to:

- Apply the concepts of force and energy to solve problems.
- Calculate the motion of a particle with a constant acceleration.
- Write down Coulomb's law and understand the meaning of all quantities involved.

SIMULATION PROBLEM #1
ELECTRIC FIELD VECTORS

You have been assigned to a team developing a new ink-jet printer. Your team is investigating the use of electric charge configurations to manipulate the ink particles in the printer. To begin design work, the company needs a computer program to simulate the electric field for complicated charge configurations. Your task is to evaluate such a program. To test the program, you use it to qualitatively predict the electric field from simple charge configurations and see if it corresponds to your expectations. You start with a single positive charge. You then try a single negative charge. Finally, you place one positive charge a short distance from a negative charge of equal magnitude to get a dipole configuration. You make a sketch of the electric field vectors at different points in space for each of the three cases.

EQUIPMENT

The computer program EM Field.

PREDICTION

Restate the problem to give a clear and complete statement of the prediction you wish to make.

WARM-UP QUESTIONS

Read: Fishbane Chapter 22 Section 1. It also might be a good idea to review Chapter 1 Section 6.

1. Draw a positively charged point object.

2. Consider a point in space some distance from that object. What is the direction of the electric field vector at this point? Remember that you can understand the electric field by considering the electric force on a positive "test charge" placed at that point. Draw the electric field vector at that point.

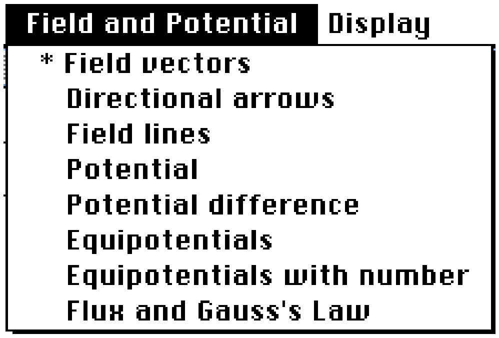
3. Consider another point in space at a different distance from the charged object. How should the length of the electric field vector at this point compare to the length of the vector at the previous point? Draw the electric field vector at this point. Choose various points in space and draw more electric field vectors. Continue this process until you have a satisfactory diagram of the electric field in the space surrounding the charge configuration.

Repeat the above steps for the other two cases. For the dipole, remember that the total electric field from multiple point charges is the vector sum of the electric fields due to each point charge. This can be understood by considering the force on a positive "test charge" and remembering that the total force is the vector sum of individual forces.

EXPLORATION

On 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 positively charged point object to the center of the window of EM Field. Select *Field vectors* from the *Field and Potential* pull-down menu (as shown).



Move the cursor where you would like to place a field vector and click the mouse button. An electric field vector should appear. Repeat this procedure until you have created a reasonable map of the electric field. To clear the EM Field window, select *Clean up screen* from the *Display* pull-down menu.

You can get another visual representation of the electric field by selecting *Directional arrows* from the *Field and Potential* menu. In this representation all arrows are the same length and the magnitude of the field is given by its color. Try this out for a single positively charged point object. If you switch to *Field vectors* without clearing the screen, you can see how the representations correspond to each other. Unfortunately, the *Directional arrows* representation is not very good for printing on black and white printers.

You can get the third visual representation of the electric field by selecting *Field Lines* in the menu. What are some differences between the "field lines" and "field vectors" representations? Are they equally useful?

Repeat your favorite electric field representation for a single negatively charged point object. How does the direction and magnitude of the electric field compare to that for the positively charged point object? Try clearing the screen and selecting a larger charge. What happens to the electric field?

Clear the screen and create a dipole by dragging two equal, but oppositely charged point objects onto the window of EM Field. You may want to use the *Show grid* and *Constrain to grid* features in the *Display* pull-down menu to position your dipole. Using your favorite electric field representation, make a map of the electric field caused by a dipole. Make sure that you carefully map the electric field at points along all axes of symmetry of the dipole.

Try a different spacing between the two charged objects making up the dipole to see how that changes the electric field map. Try larger charges.

If you are very far away from the dipole, how does the field compare to that of a single charged point object? How does it compare if you are very close to one charged object?

ANALYSIS

After making an electric field diagram of the positively charged point object, one that is negatively charged, and the dipole, print a copy of the screen for each case (select *Print Screen* from the *File* pull-down menu).

Look at the electric field diagram for your dipole. Where is the electric field the greatest? The least?

Consider one of the electric field vectors in one of the diagrams you have created. If a positively charged object were placed at the tail end of that vector, what would be the direction of the force on it? What if it were a negatively charged object? How would the size of the force compare to what it would be at a different point in space where the electric field vector was shorter or longer?

CONCLUSIONS

How does each of the computer-generated diagrams compare with your prediction? Where is the field the strongest? How is this shown in the diagram? Where is the field the weakest? How is this shown in the diagram?

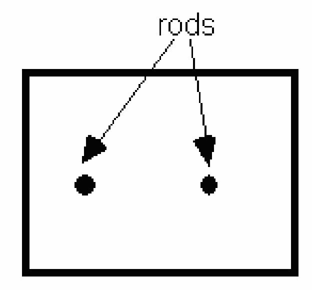
Suppose you placed a positively charged point object near the dipole. If the object began at rest, how would it move? Be careful not to confuse the acceleration of an object (determined by the total force on that object) with the velocity of the object. Try placing your object at several different points.

PROBLEM #2
ELECTRIC FIELD FROM A DIPOLE

You have a summer job with a solar power company. To measure the electric fields produced by solar cells the company plans to use conductive paper. They will arrange the cells on the paper and measure the field at different points on the paper. Your assignment is to test the process for measuring the fields. To find out if it works correctly, you decide to use it to determine the electric field created by a simple pattern of charged objects. You create a two-dimensional dipole field by giving two parallel metal rods opposite charges with a battery while their tips are in contact with a sheet of conducting paper. You then measure the electric field in the paper. To see if the paper can be used to correctly map an electric field you make a detailed qualitative prediction of the electric field produced by an electric dipole at different points in space.

EQUIPMENT

You will be using the conductive paper setup described in Appendix D. There is a coordinate grid drawn on the conductive paper. Two brass rods (electrodes) stand upright with their tips in contact with the conductive paper and connected to opposite terminals of a battery or power supply. The electric field probe is connected to a digital multimeter (DMM) set to read volts. You will also have the EM Field program. A white sheet of paper with a grid similar to the grid on the conducting paper is useful for recording the field (do not write on the conductive paper).



Overhead view of conductive paper for this problem.

PREDICTION

Restate the problem. What do you wish to predict? How can you make a qualitative prediction with as much detail as possible?

WARM-UP QUESTIONS

1. Draw a picture of the dipole similar to the one shown in the equipment section. Label one of the charged point objects "+" and the other "-".

2. At a point in space some distance from the charged objects, draw two vectors, one each to represent the electric field due to each charged object. To understand electric field you can imagine a positively charged object at that point and consider the force on that "imaginary" charged object. How should the length of each vector depend on the distance to each charged object? Measure the distance from each charged object to the point where you are drawing the vectors; make sure the relative lengths of the vectors correspond correctly to those distances.

3. Draw a darker vector representing the **total** electric field at that point. Remember, if an object feels two different forces then the total force is the vector sum of the individual forces. You can add the vectors representing electric fields due to the positive and negative parts of the dipole graphically.

4. Repeat the process at different points until you have a satisfactory map of the electric field in the space surrounding the dipole. Where is the field the strongest? The weakest? What is the direction of the field on different points along the dipole's two axes of symmetry?

EXPLORATION

You can compare your prediction with a field map of *2D charged rods* produced by the EM Field simulation program, located on the desktop. For instructions on how to use this program see the Exploration section of Problem 1.

Appendix D tells how to use the DMM and the power supply. Follow the instructions given there to set up the conductive paper.

Once the rods are connected to the battery, set the digital multimeter (DMM) to volts and turn it on. Place the tips of the probe on the conductive paper midway between the tips of the two rods. Based on your warm-up questions, what is the direction of the electric field at that position? Rotate the probe so that the center of the probe stays in the same spot. Record the meter readings as you rotate the probe. Do the values change (pay attention to the sign)? Is there a minimum or maximum value? Are there any symmetries in this data? If there are large fluctuations, determine how you will measure consistently. Describe how you will use the probe to determine the field **direction** at other points.

Now place the field probe near, but not touching, one of the rods and rotate the probe as you did before. Record your data. Determine the direction of the electric field. Compare the maximum DMM reading at this point to the one you found at the midway point. Compare your measurements to your prediction; does the value displayed on the DMM become larger or smaller when the electric field becomes stronger? Describe how you will use the probe to determine the electric field **strength** at other points.

Where on the conductive paper is the electric field strongest? weakest? Does this match your predictions?

Complete your measurement plan for mapping the electric field on the conductive paper. How will you record the magnitude and direction of the electric field at each point?

MEASUREMENT

Select a point on the conductive paper where you wish to determine the electric field. Place the probe on the conductive paper at that point and rotate until you have found the direction of the electric field. Record the magnitude and direction of the field at that point by drawing a vector in your lab journal or on a sheet of white paper with a grid pattern similar to that on the conductive paper. At each point, take at least two measurements of magnitude and direction to gain a measure of your uncertainty.

Repeat for as many points as needed to check your prediction. When you have taken enough data, you will have a map of the electric field.

CONCLUSIONS

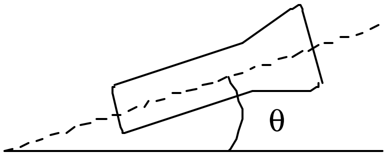
How does your map compare to your prediction? How does it compare to the simulation program? Where is the field strongest? How do you show this in your map? Where is the field weakest? How do you show this in your map?

PROBLEM #3
GRAVITATIONAL FORCE ON THE ELECTRON

You work in a research laboratory that is attempting to make a better electron microscope. The project requires precise control of a beam of electrons. For your study of electron control you decide to use a Cathode Ray Tube (CRT), the same device that is the basis of most TV sets. In the CRT, electrons are emitted at one end of an evacuated glass tube and are detected by their interaction with a phosphorous screen on the other end. Every object near the Earth's surface is subject to the gravitational force. From your physics experience you also know that the acceleration of all objects in free fall is the same, independent of their mass. Your teammates worry that the gravitational force will deflect the electron from its path giving it a parabolic trajectory, and that this deflection will depend on whether the beam is vertical or horizontal. You decide to compute how far the beam deviates from a straight-line trajectory when the beam is aimed in different directions.

EQUIPMENT

You will be using the Cathode Ray Tube (CRT) described in Appendix D. The fluorescent screen has a one-half centimeter grid in front of it so you can measure the position of the beam spot.



PREDICTION

Restate the problem. State clearly what you're going to study. Sketch a graph of the distance of the electron from the center of the CRT when it hits the screen (its deflection) versus the angle of incline of the CRT from the horizontal. Explain your reasoning.

WARM-UP QUESTIONS

Read: Fishbane Chapter 22 Section 4 and review Chapter 3 Section 4.

1. Draw a picture of the CRT in the horizontal position. Do not include the deflection plates shown in Appendix D since they will not be used in this problem. Draw the electron's trajectory from the time it leaves the electron gun until it hits the screen. Label each important kinematics quantity in the problem. Label all forces on the electron during this time. Choose a convenient coordinate system and put it on your drawing. Does the vertical component of the electron's velocity change? Why? Does the horizontal component of its velocity change? Why?

2. Calculate the velocity of the electron just after it leaves the electron gun.

Hint: The change in the electric potential energy of an electron moving from one plate to another is the voltage difference between the two plates (V_{acc} in Appendix D) times the electron's charge. What assumptions must you make to calculate the electron's initial velocity?

3. What physics principles can you use to calculate how far the electron falls below a straight-line trajectory (its deflection from the center of the screen)? What quantities must you know to make the calculation? Make the calculation.

4. Does your solution make sense? You can check by estimating the time of flight of the electron based on its initial velocity and the distance between its starting point and the screen. In that amount of time, how far would a ball drop in free fall? If the solution does not make sense, check your work for logic or algebra mistakes.

5. Now return to step 1 and solve the problem for a CRT pointed upward, and then at an angle from the horizontal.

Hint: Keep the coordinate system you used and look for the new components of the acceleration and the velocity in that frame. What difference will this make to your solution? Does the deflection increase or decrease as the tube becomes more vertical? Is there any angle for which you predict zero deflection?

EXPLORATION

WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. The **power** must be turned **off** and you must **wait** at least one minute before any wires are disconnected from or connected to the power supply. Never touch the conducting metal of any wire**.**

Follow the directions in Appendix D for connecting the power supply to the CRT. Check to see that the connections from the power supply to the high voltage and the filament heater are correct, *before* you turn the power supply on. You should have between 250 and 500 Volts of electric potential between the cathode and anode. After a moment, you should see a spot that you can adjust with the knob labeled “Focus”. If your connections are correct and the spot still does not appear, inform your lab instructor.

Do you expect the gravitational deflection to vary as a function of the angle of the CRT with the horizontal? Try different orientations in the horizontal plane to see if you can observe any difference. Does the qualitative behavior of the electron deflection agree with your prediction?

For what orientation of the CRT is it impossible for the gravitational force to deflect the electron? This is the location of the beam spot when there is no gravitational effect on the motion of the electrons.

If you observe a deflection of the electron beam, determine if this deflection is or is not caused by the gravitational force. If it is not, what does this mean and how can you minimize the effect of that force on your measurements? Is the deflection different if you move the CRT to a different position in the room?

Devise a measuring scheme to record the angle of the CRT and the position of the beam spot.

Write down your measurement plan.

MEASUREMENT

Measure the position of the beam spot at an orientation of the CRT for which you expect the gravitational deflection to be zero and the position at an angle for which the gravitational deflection should be maximum. Make measurements at several intermediate angles as well.

Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix A) and with your estimated uncertainty (see Appendix B). Otherwise, the data is nearly meaningless.

ANALYSIS

Make a graph of the position of the electron beam spot as a function of the angle that the CRT makes with the horizontal.

If you observe a deflection, how can you tell if it is caused by the gravitational force? If the deflection is not caused by gravity, what might be its cause? How will you decide?

Use your data to determine the magnitude of the deflection of the electron.

CONCLUSION

Did your data agree with your predictions? Did you observe any deflection of the electron beam? Was it in the direction you expected? What could account for any aberrant behavior? How can you arrange your CRT to minimize the aberrant behavior?

Can you measure the effect of the Earth's gravitational force on the motion of the electrons in the CRT? State your results in the most general terms supported by your data. Based on your results, do you think you need to take gravitational deflection into account when using the CRT? Why?

PROBLEM #4
DEFLECTION OF AN ELECTRON BEAM BY AN ELECTRIC FIELD

You are attempting to design an electron microscope. To precisely steer the beam of electrons you will use an electric field perpendicular to the original direction of the electrons. To test the design, you must determine how a *change in the applied electric field* affects the position of the beam spot. A colleague argues that an electron's trajectory through an electric field is analogous to a bullet's trajectory through a gravitational field. You are not convinced but are willing to test the idea. One difference that you both agree on is that the electrons in the microscope will pass through regions with an electric field and other regions with no electric field, while a bullet is always in a gravitational field. You decide to model the situation with a Cathode Ray Tube (CRT) in which electrons are emitted at one end of an evacuated glass tube and are detected by their interaction with a phosphorous screen on the other end. You will calculate the deflection of an electron that begins with an initial horizontal velocity, passes between a pair of short metal plates that produce a vertical electric field between them, and then continues through a region with no electric field until hitting the screen. Your result could depend on the strength of the electric field, the electron's initial velocity, intrinsic properties of the electron, the length of the metal plates that produce the vertical electric field, and the distance from the end of the metal plates to the screen. *NOTE: In the next lab problem you will measure the effect of changing the electron's initial speed.*

EQUIPMENT

You will use a Cathode Ray Tube (see Appendix D). Connecting the internal parallel plates to a battery or power supply creates an applied electric field. A high voltage power supply supplies the energy used to give the electron its initial velocity.

PREDICTION

Restate the problem. What do you want to calculate? What variable will you control? Present your results as an equation and as a graph.

WARM-UP QUESTIONS

For this problem, review Projectile Motion [Fishbane, 3-4], Motion of a Charge in a Field [Fishbane,22-4] and Appendix D [lab Manual]:

These questions are similar to those for Problem #5. If you have already completed Problem #5, review your answers to those warm-up questions and draw a new graph. If not, you should answer the following warm-up questions.

1. Examine the diagram of the CRT in Appendix D. You will use only one set of the deflection plates shown. Draw a simplified diagram of an electron with an initial horizontal velocity about to enter the region between the plates. Draw the screen some distance past the end of the plates. Label the relevant distances. Assume that the electric field is vertically oriented in the region between the plates and is zero elsewhere. Indicate on your picture where an electron experiences electrical forces. Draw a coordinate axis on this picture. Sketch the electron's trajectory through the CRT, indicating where the electron should accelerate and the direction of that acceleration. Indicate on the screen of the CRT the distance by which the electron has been deflected away from its initial straight-line path. Why can you ignore the gravitational force on the electron?

2. Recall some things you already know about projectile motion. Does a force in the vertical direction affect the horizontal component of an object’s velocity? In this situation, can you use the horizontal velocity component to find the time required to travel some horizontal distance?

3. Consider the motion of the electron in the region between the deflection plates. Calculate the amount of time the electron spends in this region. Calculate the vertical position and vertical velocity component of the electron when it leaves this region. Remember you are assuming that only an electric force acts on the electron and are neglecting the gravitational force. (You will need the relationship between the electric field and the electric force on a charged object, as well as the general relationship between force and acceleration.)

4. Consider the motion of the electron in the region past the deflection plates. What is true about the vertical and horizontal components of its velocity in this region? Calculate where the electron hits the screen relative to where it entered this final region. Then calculate the total deflection of the electron at the screen from where it initially entered the region between the plates.

5. Using the equation you have found for the deflection of the electron beam draw a graph of the deflection vs. the electric field strength. Treat the other quantities as constant.

6. Two quantities in your expression are not directly measurable in lab. These are the electron’s initial velocity and the electric field strength between the deflection plates. You will, however, know the voltage that accelerates the electrons, V_{acc} , and the voltage across the deflection plates, V_{plates} . Use conservation of energy to express the electron’s initial velocity in terms of V_{acc} . Substitute this expression into your deflection equation.

If you have already learned about potential differences, you may not need the following hint <based on Fishbane section 24-2; also see problem 24-24>: the magnitude of the work done on the electron by the accelerating voltage equals V_{acc} times the electron charge.

7. Write an equation relating V_{plates} to the electric field between the plates, and substitute it into your deflection equation. Your final deflection equation should involve only quantities that can be measured in lab or found in the textbook or in Appendix D.

If you have already learned about potential differences, you may not need the following hint <from Fishbane 24-5>: the electric field between the plates equals V_{plates} divided by the distance between the plates.

EXPLORATION

WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. To avoid danger, the **power** must be turned **off** and you must **wait** at least one minute before any wires are disconnected from or connected to the power supply. Never touch the conducting metal of any wire.

Follow the directions in Appendix D for connecting the power supply to the CRT. Check to see that the connections from the power supply to the high voltage and the filament heater are correct, before you turn the power supply on. You should have between 250 and 500 volts of electric potential between the cathode and anode. After a moment, you should see a spot that you can adjust with the knob labeled "Focus". If your connections are correct and the spot still does not appear, inform your lab instructor.

Before you turn on the electric field between the deflection plates, make a note of the position of the spot on the screen. The deflections you measure will be in relation to this point. Make sure not to change the position of the CRT since external fields may affect the position of the spot.

Now apply a voltage across one set of deflection plates, noting how the electron beam moves across the screen as the voltage is increased. Determine how you will adjust the voltage level and how you will measure it. Write down the range of voltages for which you can make a good measurement. Repeat this procedure for the perpendicular set of deflection plates.

If you cannot make the electron spot sweep entirely across the screen, try changing the voltage between the anode and the cathode that you originally set somewhere between 250 and 500 volts. This voltage changes the electron's velocity entering the deflection plates. Select a voltage between the anode and cathode that gives you a useful set of measurements for your deflections.

Devise a measuring scheme to record the position of the beam spot. Be sure you have established the zero deflection point of the beam spot. Write down your measurement plan. How will you determine the strength of the electric field between the deflection plates? What quantities will you hold constant for this measurement? How many measurements do you need?

MEASUREMENT

Measure the position of the beam spot as you change the electric field applied to the deflection plates. At least two people should make a measurement at each point, so you can estimate measurement uncertainty. *Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix A) and with your estimated uncertainty (see Appendix B). Otherwise, the data is virtually meaningless.*

ANALYSIS

Draw a graph of the measured deflection of the electron beam as a function of the voltage difference across the deflector plates.

CONCLUSIONS

How does the graph based on your data compare to the graph based on your prediction? If they are different explain why. Is the analogy between bullets and electrons supported by your experiment?

How does the deflection of the electron beam vary with the applied electric field? State your results in the most general terms supported by your data.

PROBLEM #5
DEFLECTION OF AN ELECTRON BEAM AND VELOCITY

You are attempting to design an electron microscope. To precisely steer the beam of electrons you will use an electric field perpendicular to the original direction of the electrons. To test the design, you must determine how *a change in the initial velocity of the electrons* affects the position of the beam spot. A colleague argues that an electron's trajectory through an electric field is analogous to a bullet's trajectory through a gravitational field. You are not convinced but are willing to test the idea. One difference that you both agree on is that the electrons in the microscope will pass through regions with an electric field and other region with no electric field, while a bullet is always in a gravitational field. You decide to model the situation with a Cathode Ray Tube (CRT) in which electrons are emitted at one end of an evacuated glass tube and are detected by their interaction with a phosphorous screen on the other end. You will calculate the deflection of an electron that begins with an initial horizontal velocity, passes between a pair of short metal plates that produce a vertical electric field between them, and then continues through a region with no electric field until hitting the screen. Your result could depend on the strength of the electric field, the electron's initial velocity, intrinsic properties of the electron, the length of the metal plates that produce the vertical electric field, and the distance from the end of the metal plates to the screen.

EQUIPMENT

You will use a Cathode Ray Tube (see Appendix D).

PREDICTION

Restate the problem in terms of what you want to calculate and which parameter you will vary? Show your prediction in the form of an equation and a graph.

WARM-UP QUESTIONS

For this problem, review Projectile Motion [Fishbane, 3-4], Motion of a Charge in a Field [Fishbane,22-4] and *Appendix D* [lab Manual].

These questions are similar to those for Problem #4. If you have already completed Problem #4, review your answers to those warm-up questions and draw a new graph. If not, you should answer the following warm-up questions.

1. Examine the diagram of the CRT in Appendix D. You will use only one set of the deflection plates shown. Draw a simplified diagram of an electron with an initial horizontal velocity about to enter the region between the plates. Draw the screen some distance past the end of the plates. Label the relevant distances. Assume that the electric field is vertically oriented in the region between the plates and is zero elsewhere. Indicate on your picture where an electron experiences electrical forces. Draw a coordinate axis on this picture. Sketch the electron's trajectory through the CRT, indicating where the electron should accelerate and the direction of that acceleration. Indicate on the screen of the CRT the distance by which the electron has been deflected away from its initial straight-line path. Why can you ignore the gravitational force on the electron?

2. Recall some things you already know about projectile motion. Does a force in the vertical direction affect the horizontal component of an object's velocity? In this situation, can you use the horizontal velocity component to find the time required to travel some horizontal distance?

3. Consider the motion of the electron in the region between the deflection plates. Calculate the amount of time the electron spends in this region. Calculate the vertical position and vertical velocity component of the electron when it leaves this region. Remember you are assuming that only an electric force acts on the electron and are neglecting the gravitational force. (You will need the relationship between the electric field and the electric force on a charged object, as well as the general relationship between force and acceleration.)

4. Consider the motion of the electron in the region past the deflection plates. What is true about the vertical and horizontal components of its velocity in this region? Calculate where the electron hits the screen relative to where it entered this final region. Then calculate the total deflection of the electron at the screen from where it initially entered the region between the plates.

5. Using the equation you have found for the deflection of the electron beam draw a graph of the deflection vs. the initial velocity. Treat the other quantities as constant.

6. Two quantities in your expression are not directly measurable in lab. These are the electron's initial velocity and the electric field strength between the deflection plates. You will, however, know the voltage that accelerates the electrons, V_{acc} , and the voltage across the deflection plates, V_{plates}. Use conservation of energy to express the electron's initial velocity in terms of V_{acc} . Substitute this expression into your deflection equation.

If you have already learned about potential differences, you may not need the following hint <based on Fishbane section 24-2; also see problem 24-24>: the magnitude of the work done on the electron by the accelerating voltage equals V_{acc} times the electron charge.

7. Write an equation relating V_{plates} to the electric field between the plates, and substitute it into your deflection equation. Your final deflection equation should involve only quantities that can be measured in lab or found in the textbook or in Appendix D. If you have already learned about potential differences, you may not need the following hint <from Fishbane 24-5>: the electric field between the plates equals V_{plates} divided by the distance between the plates.

EXPLORATION

WARNING: You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. To avoid danger, the **power** must be turned **off** and you must **wait** at least one minute before any wires are disconnected from or connected to the power supply. Never touch the conducting metal of any wire.

Follow the directions in *Appendix D* for connecting the power supply to the CRT. Check to see that the connections from the power supply to the high voltage and the filament heater are correct, *before* you turn the power supply on. Apply between 250 and 500 Volts across the anode and cathode. After a moment, you should observe a spot on the screen that can be adjusted with the knob labeled "Focus". If your connections are correct and the spot still doesn't appear, inform your lab instructor.

TAKING EXTREME CARE, change the voltage across the accelerating plates, and determine the range of values for which the electrons have enough energy to produce a spot on the screen. Changing this voltage changes the velocity of the electrons as they enter the deflection plates. What is the range of initial electron velocities corresponding to this range of accelerating voltages? Which of these values will give you the largest deflection when you later apply an electric field between the deflection plates?

Before you turn on the electric field between the deflection plates, make a note of the position of the spot on the screen. The deflections you measure will be in relation to this point. Make sure not to change the position of the CRT since external fields may affect the position of the spot.

Now apply a voltage across one set of deflection plates, noting how the electron beam moves across the screen as the voltage is increased. Find a voltage across the deflection plates that allows the deflection for the entire range of initial electron velocities to be measured as accurately as possible.

Devise a measuring scheme to record the position of the beam spot. Be sure you have established the zero deflection point of the beam spot.

Write down your measurement plan. How will you determine the strength of the electric field between the deflection plates? How will you determine the initial velocity of the electrons? What quantities will you hold constant for this measurement? How many measurements do you need?

MEASUREMENT

Measure the deflection of the beam spot as you change the initial velocity of the electrons in the beam, keeping the electric field between the deflection plates constant. At least two people should make a measurement at each point, so you can estimate measurement uncertainty. *Note: Be sure to record your measurements with the appropriate number of significant figures (see Appendix A) and with your estimated uncertainty (see Appendix B). Otherwise, the data is virtually meaningless.*

ANALYSIS

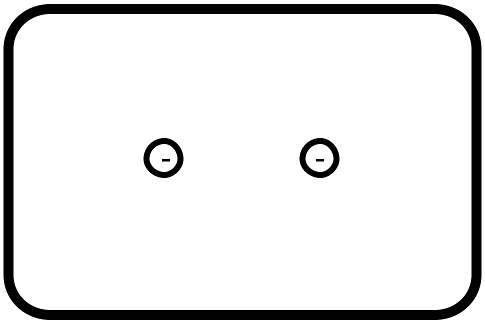
Draw a graph of your average measurements of the deflection of the electron beam as a function of the initial electron velocity. How do your uncertainties affect your graph?

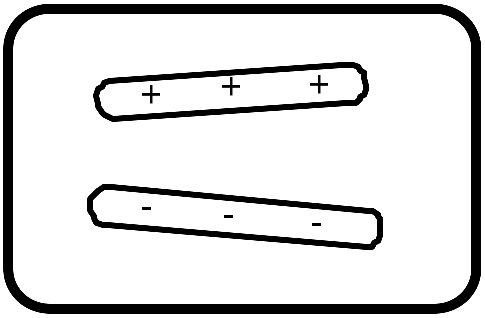
CONCLUSIONS

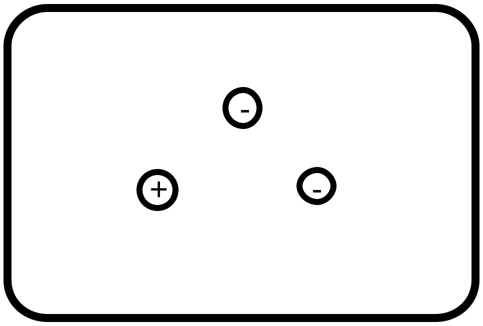
Did your data agree with your prediction of how the electron beam would deflect due to the initial electron velocity? If not, why? How does the deflection of the electron beam vary with initial electron velocity? State your results in the most general terms supported by your data.

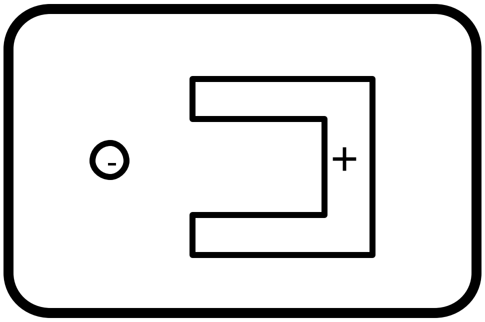
☑ CHECK YOUR UNDERSTANDING

1. For each of the charge configurations below, map the electric field. Assume that each object is made of metal and that the trays are filled with water.



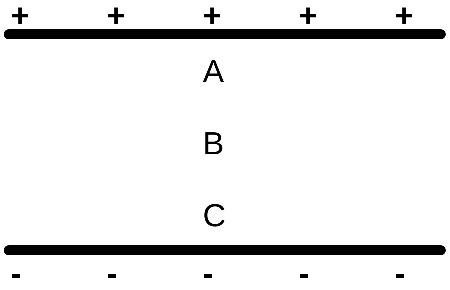






2. For a CRT with the same plates and electron gun as you used in lab, assume that the distance from the center of the Vx plate to the fluorescent screen is 10 cm and the distance from the center of the Vy plate to the screen is 8 cm. If Vacc is 300V, Vx = -8V and Vy = 3V, what is the displacement of the electron beam?

3. Assume you have two infinite parallel planes of charge separated by a distance d as shown below. Use the symbols <,>, and = to compare the force on a test charge, q, at points A, B, and C.



TA Name:____________________________

PHYSICS 1302 LABORATORY REPORT

Laboratory I

Name and ID#: ______________________________

Date performed: ____________ Day/Time section meets: ______________________

Lab Partners' Names: ______________________________

____

____

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.