

## **LABORATORY IV**

### **ELECTRIC FIELDS AND FORCES**

Action-at-a-distance forces (gravitational, electric, and magnetic) make up a common part of your everyday experiences. These forces are difficult to fit into our physical intuition for two reasons. First, it is hard to conceive of objects interacting when they are not in contact. Second, objects that interact by these action-at-a-distance forces create systems that have potential energy. The question naturally arises: Where is this potential energy?

The conceptual difficulties of both the force and the potential energy for an action-at-a-distance interaction are solved through the concept of a field. Under field theory, an object affects the space around it and creates a field. Another object entering this space is affected by that field and may experience a force. The fields interact with each other, not the objects. One object causes a field and the other object's field interacts directly with the first field. When two objects interact in this way we envision the potential energy as residing in the field.

Using fields to study interactions solves the intellectual puzzle of action-at-a-distance. Field theory, however, is a much more abstract way of thinking about the world. The only reason we use field theory is because it leads us to a deeper understanding of natural phenomena and inspires the invention of new devices. The problems in this laboratory are primarily designed to give you practice visualizing fields and using the field concept to solve problems.

You will first explore electric fields by building different configurations of charged objects and mapping their electric fields in a water tray. In the final problems of this lab, you will measure the behavior of electrons as they travel through an electric field.

#### **OBJECTIVES:**

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

- Qualitatively construct the electric field based on the geometry of charged objects;
- Determine the magnitude and direction of the force on a charged particle in a given electric field.

**PREPARATION:**

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 of the quantities involved.

## **PROBLEM #1: ELECTRIC FIELD VECTORS**

As part of your internship with a local computer printer company, 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 help the design work, the company needs a computer program to simulate the electric field for complicated charge configurations. The lead engineer has assigned you the task of evaluating 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 form your expectations from your knowledge of the force that would be exerted on positive charge. To accomplish this task, you start with a single positive charge. You then try a single negative charge. Finally, you add them together to get a dipole configuration.

### **EQUIPMENT**

You will use the computer program EM Field. This program will draw the electric field vector at any point near any given charge distribution.

### **PREDICTION**

Using your knowledge of the forces exerted by charged objects, draw vectors representing the electric field around the following charge distributions: (i) A positively charged point object; (ii) A negatively charged point object; (iii) A dipole (two equal but oppositely charged point objects separated by a small distance). As usual, the length of the vector should represent the magnitude of the field. In each case, draw enough vectors to give a qualitative idea of the behavior of the field. Where do you think the electric field will be the strongest? The weakest?

### **WARM-UP**

Read Serway & Vuille, Chapter 15, Sections 15.1, 15.3, 15.4, and 15.5 (or Cutnell & Johnson 18.5, 18.6 and 18.7)

1. Draw a positively charged point object.
2. At a point in space some distance from that object, imagine you have another positively charged point object. Draw a vector representing the force on that “imaginary” object.
3. Now move your “imaginary” positively charged object to another point in space and draw the vector representing the force on it. How does the magnitude of the force on the “imaginary” object

## PROBLEM #1: ELECTRIC FIELD VECTORS

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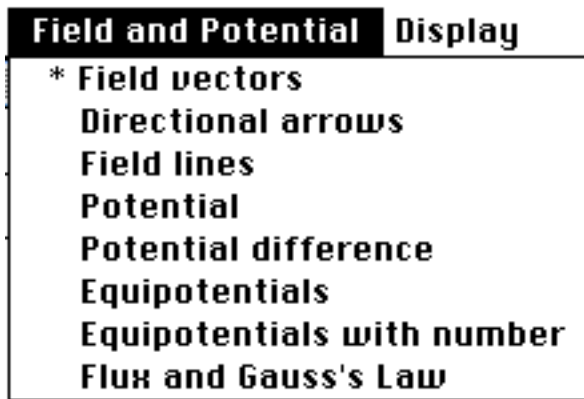
depend on its distance from the original positively charged point object? Make sure the length of your vector represents this dependence. Continue this process until you have a satisfactory map of the electric field in the space surrounding the original positively charged point object.

Repeat the above steps for a negatively charged point object and a dipole. For the dipole, remember that if two objects exert a force on a third object, the force on that third object is the **vector sum** of the forces exerted by each of the other objects.

### EXPLORATION

Before beginning to use the computer simulation, do a quick check to see if the program works the way you think it should.

Open EM Field and click anywhere in the window for the instructions. From the *Sources* pull-down menu, select *3D 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. You can get a third visual representation of the electric field by selecting *Field lines* from the *Field and Potential* menu. This representation creates a line that follows the direction of force with the lines color representing its strength at a given location. If you switch to *Field vectors* without clearing the screen, you can see how the representations correspond to each other. Unfortunately the *Directional arrows* and *Field lines* representations are not very good for printing on black and white printers.

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 lay out 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 you made an electric field map 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).

Looking at the electric field map of your dipole, imagine a positively charged point object at the tail position of each vector. Compare the force on that “imaginary” object with the force on it if you moved it to another position. Where is the force on the “imaginary” object the greatest? The least? What would be true of the force if the “imaginary” object was negatively charged?

**CONCLUSION**

How does each of these maps compare with your prediction? Where is the field the strongest? How is this shown in your map? Where is the field the weakest? How is this shown in your map?

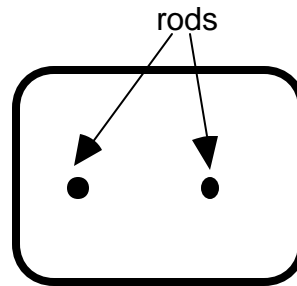
Suppose you placed a positively charged “imaginary” point object near your dipole. If the imaginary object started at rest how would it move? Be careful not to confuse the acceleration of an object (which is determined by the total force on that object) with the velocity of the object. Try starting your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

## PROBLEM #2: THE ELECTRIC FIELD FROM A DIPOLE

You have a summer job with a company that designs and manufactures measuring instruments for research laboratories. Your boss has asked you to test a new instrument that is designed to measure electric fields underwater. To become familiar with how it works, you decide to first use the instrument to determine the pattern of an electric field that you already know. You create a two-dimensional dipole field by giving two parallel metal rods opposite charges with a battery while their ends are placed on electrostatic paper, which conducts electricity similarly to water. You then measure the electric field on the paper.

### EQUIPMENT

You will be using the Electrostatic Paper setup, which consists of one piece of electrostatic paper, two brass electrode rods, several banana cables and alligator clips, a battery, and a wood block to increase contact pressure between the electrodes and the paper. Measurements will be made using a Digital Multimeter (DMM) set to read volts and a pin tip probe as described in Appendix A.



Overhead view of  
electrostatic paper for this  
problem.

### PREDICTION

Draw a sketch of the pattern of the electric field created in a plane perpendicular to two parallel metal rods with opposite charges. Record where do you think the electric field will be the strongest, and where you think it will be the weakest.

When you get to lab, check your sketch by making a field map of *2D charged rods* using the [EM Field simulation](#).

### WARM-UP

Read Serway & Vuille, Chapter 15, Sections 15.1, 15.3, 15.4, and 15.5 (or Cutnell & Johnson 18.5, 18.6 and 18.7)

1. Draw a positively charged point object.

2. At a point in space some distance from that object, imagine you have another positively charged point object. Draw a vector representing the force on that “imaginary” object.
3. Now move your “imaginary” positively charged object to another point in space and draw the vector representing the force on it. How does the magnitude of the force on the “imaginary” object depend on its distance from the original positively charged point object? Make sure the length of your vector represents this dependence. Continue this process until you have a satisfactory map of the electric field in the space surrounding the original positively charged point object.
4. Repeat the above steps for a negatively charged point object and a dipole. For the dipole, remember that if two objects exert a force on a third object, the force on that third object is the **vector sum** of the forces exerted by each of the other objects.

### EXPLORATION

Remember that the purpose of this problem is to become familiar with both (a) the electric field on the electrostatic paper and (b) the electric field probe. Start by setting up the electrostatic paper as instructed in Appendix A. Once the rods are connected to the battery, set the digital multi-meter (DMM) that is connected to the electric field probe to the “volts” setting and turn it on. Place the tips of the probe on the paper midway between the tips of the two rods. Rotate the probe so it stays on the paper and the center of the probe stays in the same spot. Record the meter readings as you rotate the probe. Do the values change? Is there a minimum or maximum value? Are there any symmetries in this data?

The DMM displays the largest value when the electric field on the paper at that position is parallel to the imaginary line that connects the two probe tips. If the value on the display is negative, the electric field is in the opposite direction as when it is positive. Using the data you have already collected, determine the direction of the electric field at the point midway between the two electrodes? Is this the direction you expected? Why?

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 value you found at the midway point to that near an electrode when the probe is aligned with the electric field.

The value displayed on the DMM is larger for a stronger electric field. Where is the electric field on the paper the strongest? Is this where you expected it to be? Why?

### MEASUREMENT

Select a point in the electrostatic paper where you wish to determine the electric field. Place the probe on the 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 (the length of the vector proportional to the value displayed on the DMM).

Repeat for as many points as you need to accurately map the electric field to check your prediction. When you have taken enough data, your finished product is a **map** of the electric field.

**CONCLUSION**

How does your map compare to your prediction? Where is the field the strongest? How is this shown in your map? Where is the field the weakest? How is this shown in your map?

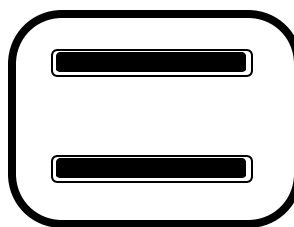


### **PROBLEM #3: THE ELECTRIC FIELD FROM PARALLEL CHARGED PLATES**

The research laboratory that you are working in is designing an electrostatic deflector for an air purification system. Your supervisor has assumed that the electric field between two charged plates is constant and always perpendicular the surface of the plates. Every other electric field you know weakens as you move further away from the charged surface. You decided to test this assumption by mapping the electric field between two parallel plates using electrostatic paper.

#### **EQUIPMENT**

You will be using the Electrostatic Paper setup, which consists of one piece of electrostatic paper, two brass electrode rods, several banana cables and alligator clips, a battery, and a wood block to increase contact pressure between the electrodes and the paper. You will also have two slender copper plates that will be placed at the end of each electrode. Measurements will be made using a Digital Multimeter (DMM) set to read volts and a pin tip probe as described in Appendix A.



Overhead view of electrostatic paper for this experiment.

#### **PREDICTION**

Make a sketch of the electric field pattern for the charge configuration on the electrostatic paper. Label areas where you expect the field to be strongest and where it should be weakest. Is there an area where the field is relatively constant?

When you get to lab, use the [EM Field](#) simulation to check your sketch of the electric field between two parallel plates.

#### **WARM-UP**

Read Serway & Vuille, Chapter 15, Sections 15.1, 15.3, 15.4, and 15.5 and Chapter 16, Section 16.6 (or Cutnell & Johnson 18.5, 18.6, and 18.7)

1. Draw a horizontal plate as made up of a line of point charges.

### PROBLEM #3: THE ELECTRIC FIELD FROM PARALLEL CHARGED PLATES

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2. Qualitatively determine the electric field at some point above that line of charges by adding together the contributions at that point due to all of the charges' electric fields. One way to do this is to start with one charge and draw the electric field vector at some point above it. Note the direction of the electric field. Now add a charge at an equal distance on each side of the original charge. At the point of interest draw the electric field vector from all three charges. From your drawing get the sum of these vectors and note its direction. Continue by adding two more charges to each end of the line and repeat the vector sum. What do you think will be the direction of the electric field as you add a very large number of charges in this way?
3. If the line of charges is infinite, the procedure in step 2 will give you the direction of the field at every point above the plate. What does this tell you about the direction of the electric field at every point above or below the infinite plate?
4. Now sketch the situation for two parallel plates with opposite charge. At a point between them draw the electric field vector from each plate and add them. Repeat for a selection of points between the two plates.
5. Repeat step 4 for the regions outside the plates.

#### EXPLORATION

Use the same equipment as in Problem #1. Review your journal to familiarize yourself with how to use the electrostatic paper and electric field probe (or see Appendix A).

Place the two slender metal plates on the paper and place a brass electrode on each. Then connect one electrode to each terminal of a battery or power supply.

How should you determine how far apart the plates should be? How many data points do you need between the plates? How many do you need outside the plates? Do the plates need to be perfectly parallel?

Outline your measurement plan.

#### MEASUREMENT

Map the electric field on the paper from two opposite-charged parallel plates. Your map should show both the magnitude and direction of the electric field. Be sure you map the field outside the plates as well as between the plates.

#### CONCLUSION

How does the map of the electric field compare to your prediction? Why? Is your supervisor's assumption that the electric field between the plates is constant justified? Is there a region in which the assumption is not valid? If you are very close to a charged surface, what is the direction of the electric field relative to that surface?

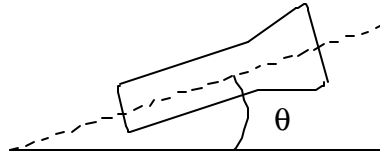
## **PROBLEM #4: GRAVITATIONAL FORCE ON THE ELECTRON**

You are working in a research laboratory that is attempting to make a better electron microscope. The key to advancing the project is the precise control of a beam of electrons. To study this, you decide to use a Cathode Ray Tube (CRT), the same device that is the basis of TV sets and most computer screens. In a 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 (you see them glow).

You know that every object in flight 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. Even though an electron has a small mass, it has the same gravitational acceleration as a baseball or a bullet. You worry that the gravitational force will deflect the electron from its path giving it the parabolic trajectory that you studied in the first term of physics.

### **EQUIPMENT**

You will be using the Cathode Ray Tube (CRT) described in Appendix A. The fluorescent screen has a half centimeter grid in front of it so you can measure the position of the beam spot. Along with the CRT you will need several banana cables and a Cenco power supply.



### **PREDICTION**

Calculate how far an electron falls during its flight within the CRT when the CRT is *horizontal* ( $\theta = 0^\circ$ ), as a function of the initial velocity of the electron. Assume that the initial velocity is along the central axis of the CRT.

Based on your knowledge of kinematics, predict if this electron deflection (distance from the center of the CRT at the screen) will increase, decrease or stay the same as the angle is increased from horizontal ( $\theta = 0^\circ$ ) to vertical ( $\theta = 90^\circ$ ). Make a graph of the electron deflection-versus-angle of incline of the CRT from the horizontal. Explain your reasoning.

**WARM-UP**

Read Serway & Vuille, Chapter 16, Sections 16.1 and 16.2. Review Chapter 3, Section 3.4 to refresh your knowledge of projectile motion. (or Cutnell & Johnson 19.2, 19.4, and Chapter 3)

1. Draw a sketch of the CRT in the horizontal position. Be sure to include all components as shown in Appendix A in your sketch, except the deflection plates, because you will not use them in this problem. Make sure that you understand the function of all of these parts.
2. Draw the electron's path from the time it leaves the electron gun until it hits the screen. Label all of the important kinematic quantities in the problem. The target quantity for this problem is the electron beam deflection at the screen. The quantities that you can measure in this problem are
  - (a) the position of the electron beam spot on the fluorescent screen,
  - (b) the initial electron accelerating voltage ( $V_{\text{acc}}$  in your sketch),
  - (c) the distance from the end of the electron gun to the CRT screen, and
  - (d) the angle the CRT makes with the horizontal.
3. In this projectile motion problem, you know the electron's acceleration and you need to find its initial velocity. How much potential energy does the an electron have when it first enters the acceleration plates given a voltage across the plates of  $V_{\text{acc}}$  ? Use conservation of energy to find how much kinetic energy the electron has upon leaving the acceleration plates. Given this kinetic energy, what is the electrons velocity? Assume that the direction of the electron leaving the electron gun region of the CRT is along the central axis of the tube.
4. Using the velocity of the electron and the kinematics of a projectile fired horizontally under the influence of gravity to determine how far the electrons fall as they travel down the length of the horizontal CRT.

**EXPLORATION**



**WARNING:** You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should 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 direction in Appendix A for connecting the Cenco power-supply to the CRT. *Before* you turn the power supply on, check to see that the connections from the power supply to the high voltage and the filament heater are correct. 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 to see if you can observe any difference.

For what orientation of the CRT can you find the 'zero deflection' position? This is the location of the beam spot when there is no gravitational effect on the motion of the electrons.

Devise a measuring scheme to record the angle of the CRT and the position of the beam spot and complete your measurement plan.

### MEASUREMENT

Measure the position of the beam spot with the change in angle. Try to get as many different measurements as you can as you change the CRT's angle from 0 to 90°.

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

### ANALYSIS

Use your data to graph the position of the electron beam spot versus the angle the CRT makes with the horizontal.

If you observe a deflection, how can you tell if the gravitational force causes it? What else could cause a deflection?

### CONCLUSION

Does the Earth's gravitational force affect the motion of the electrons in the CRT in a measurable way? When you deflect the electron beam by an electric field what correction will you need to apply to account for the gravitational field?

Did your data agree with your predictions? Did you observe any deflection of the electron beam? Was it in the direction you expected? Was it bigger or smaller than you expected? What could account for any unusual behavior?

## **PROBLEM #5: DEFLECTION OF AN ELECTRON BEAM BY AN ELECTRIC FORCE**

You have been attempting to design a better electron microscope. To precisely control the beam of electrons you will use electric fields in the two directions perpendicular to the original direction of the electrons. For your study of electron control you decide to use a Cathode Ray Tube (CRT) in which the electron passes between one set of parallel plates in the horizontal direction and another set in the vertical direction. 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. The electric fields should be sufficient to sweep the electron beam completely across the screen. Before you can test the sensitivity of the electron microscope design, you will need to determine how an applied electric field affects the position of the beam spot.

### **EQUIPMENT**

You will be using the Cathode Ray Tube described in Appendix A. The fluorescent screen has a half centimeter grid in front of it so you can measure the position of the beam spot. Along with the CRT you will have several banana cables, a Cenco power supply, and a Digital Multimeter (DMM) Connecting the internal parallel plates to the power supply creates the applied electric field. The DMM will let you measure the voltage going to the parallel plates.

### **PREDICTION**

Calculate how the deflection of the electron spot depends on the electric field between the horizontal deflection plates. Repeat for the vertical deflection plates.

Use this equation to make a graph of deflection versus applied electric field strength for each set of deflection plates.

### **WARM-UP**

Read Serway & Vuille, Chapter 16, Sections 16.1 and 16.2. Review Chapter 3, Section 3.4 to refresh your knowledge of projectile motion. (or Cutnell & Johnson 19.2, 19.4, and Chapter 3)

1. Draw a picture of the pertinent components of the CRT. Only include one set of the deflecting plates shown in Appendix A. Draw a coordinate axis on this picture. Draw the electron trajectory. On the trajectory, draw and label arrows representing the electron's velocity and acceleration in each region of the CRT.
2. Where in your picture will an electron experience an acceleration? What force causes this acceleration? Draw an arrow representing the force on your picture. What forces are you assuming are negligible? In the region of acceleration, make a motion diagram showing the electron's

trajectory and showing the electron's velocity and acceleration when the electron enters the region, is in the region, and leaves the region.

3. Write an expression for the velocity of the electrons as they leave the electron gun in the CRT, in terms of the accelerating voltage.
4. Determine how much the electron beam is deflected as it travels perpendicular to the electric field between the deflecting plates (that are set to a voltage  $V_y$ ).

Write down a relationship between electric field and the force on the electron. How are force and acceleration related? Is the acceleration constant as the electron travels between the two plates?

Note: The electric field between two equally charged parallel plates is equal to the voltage between the two plates ( $V_y$ , in Volts) divided by the distance between the plates (in meters).

Write down the equation giving the electron's position as it emerges from the deflecting plates. Write another equation giving the electron's direction.

Note: If the acceleration is constant, then the electron follows a projectile path even if the acceleration is not from gravity.

5. Draw the electron's trajectory from the time it leaves the deflecting plates until it strikes the screen. In this region, is the electron accelerating? If so, what force(s) cause this acceleration? What forces can you assume are negligible, if any? Use some geometry to write an equation giving the distance from the center the electron strikes the screen. This is the deflection.
6. Write down an equation giving the deflection of an electron from question 5. Determine the quantities that are known and those that are unknown. Write down the equation(s) from question 4 you could use to solve for the unknown(s). If there are any additional unknowns, write down the equation from question 2 that you could use to solve for one of them. If you have an independent equation for each unknown, you can solve the problem. If not review your pictures to see if you can extract any additional information to write down equations for any unknowns not accounted for in the above procedure.
7. Use your equation to sketch a graph of position of the beam spot versus the applied electric field.

### EXPLORATION

*This exploration is similar to that of Problem #4. If you have already completed that problem, consult your lab journal for the necessary information.*



**WARNING:** You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should 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 direction in Appendix A for connecting the powers 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, find the CRT orientation that gives no deflection of the electron beam. In this position the effect of all of the outside forces on the electron is negligible.

Now slowly apply a voltage across one set of deflection plates. Note how the electron beam moves across the screen as the voltage is increased. 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.

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?

Complete your measurement plan.

**MEASUREMENT**

Measure the position of the beam spot as you change the electric field applied to the deflection plates.

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

**ANALYSIS**

Draw a graph of your Prediction equation of the deflection of the electron beam as a function of the applied electric field.

Draw a graph using your measurements of the deflection of the electron beam as a function of the applied electric field.

**CONCLUSION**

How does the graph based on your data compare to the graph based on your prediction? How does the deflection of the electron beam vary with the applied electric field? Did your data agree with your prediction of how the electron beam would deflect due to the applied electric field? If not, why?



## **PROBLEM #6: DEFLECTION OF AN ELECTRON BEAM AND VELOCITY**

You have been attempting to design a better electron microscope. To precisely control the beam of electrons you will use electric fields in the two directions perpendicular to the original direction of the electrons. For your study of electron control you decide to use a Cathode Ray Tube (CRT) in which the electron passes between one set of parallel plates in the horizontal direction and another set in the vertical direction. 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. The electric fields should be sufficient to sweep the electron beam completely across the screen. Before you can test the sensitivity of the electron microscope design, you will need to determine how the velocity of the electron leaving the electron gun region of the CRT affects the position of the beam spot.

### **EQUIPMENT**

You will be using the Cathode Ray Tube described in Appendix A. The fluorescent screen has a half centimeter grid in front of it so you can measure the position of the beam spot. Along with the CRT you will have several banana cables, a Cenco power supply, and a Digital Multimeter (DMM). Connecting the internal parallel plates to the power supply creates the applied electric field. The DMM will let you measure the voltage going to the parallel plates.

### **PREDICTION**

Determine the change in position of the electron beam as a function of initial electron velocity.

Use this equation to make a graph of the position of the beam spot as a function of the initial velocity of the electrons.

### **WARM-UP**

Read Serway & Vuille, Chapter 16, Sections 16.1, and 16.2. Review Chapter 3, Section 3.4 to refresh your knowledge of projectile motion. (or Cutnell & Johnson 19.2, 19.4, and Chapter 3)

Note: This problem is similar to what you did in problem #5. This time, you can treat the electric field between the deflection plates as a “known” quantity and the velocity of the electron entering the deflection plates as an “unknown”. You can use your answers to that problem for most of the following questions:

1. Draw a picture of the pertinent components of the CRT. Only include one set of the deflecting plates shown in Appendix A. Draw a coordinate axis on this picture. Draw the electron trajectory.

On the trajectory, draw and label arrows representing the electron's velocity and acceleration in each region of the CRT.

2. Where in your picture will an electron experience an acceleration? What force causes this acceleration? Draw an arrow representing the force on your picture. What forces are you assuming are negligible? In the region of acceleration, make a motion diagram showing the electron's trajectory and showing the electron's velocity and acceleration when the electron enters the region, is in the region, and leaves the region.
3. Write an expression for the velocity of the electrons as they leave the electron gun in the CRT in terms of the accelerating voltage.
4. Determine how much the electron beam is deflected as it travels perpendicular to the electric field between the deflecting plates (that are set to a voltage  $V_y$ ). Write down a relationship between electric field and the force on the electron. How are force and acceleration related? Is the acceleration constant as the electron travels between the two plates?

Note: If the acceleration is constant, then the electron follows a projectile path even if the acceleration is not from gravity.

Write down the equation giving the electron's position as it emerges from the deflecting plates. Write another equation giving the electron's direction. Note: The electric field between two equally charged parallel plates is equal to the voltage between the two plates ( $V_y$ , in Volts) divided by the distance between the plates (in meters).

5. Draw the electron's trajectory from the time it leaves the deflecting plates until it strikes the screen. In this region, is the electron accelerating? If so, what force(s) cause this acceleration? What forces can you assume are negligible, if any? Use some geometry to write an equation giving the distance from the center the electron strikes the screen. This is the deflection.
6. Write down an equation giving the deflection of an electron from question 5. Determine the quantities that are known and those that are unknown. Write down the equation(s) from question 4 you could use to solve for the unknown(s). If there are any additional unknowns, write down the equation from question 2 that you could use to solve for one of them. If you have an independent equation for each unknown, you can solve the problem. If not review your pictures to see if you can extract any additional information to write down equations for any unknowns not accounted for in the above procedure.
7. Use your equation to sketch the graph of position of the beam spot versus the initial electron velocity.

### EXPLORATION

*This exploration is very similar to that of Problem #5. If you have already completed that problem, consult your lab journal for most of the necessary information.*



**WARNING:** You will be working with equipment that generates large electric voltages. Improper use can cause painful burns. **To avoid danger, the power should be turned OFF and you should 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 direction in Appendix A for connecting the powers 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, find the CRT orientation that gives no deflection of the electron beam. In this position the effect of all of the outside forces on the electron is negligible.

Now slowly turn apply a voltage across one set of deflection plates. Note how the electron beam moves across the screen as the voltage is increased. Determine a voltage which gives a deflection about half of maximum measurable deflection. Repeat this procedure for the perpendicular set of deflection plates.

The electric field between two equally charged parallel plates is equal to the voltage between the two plates (in Volts) divided by the distance between the plates (in meters).

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

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. How will you determine the electron's velocity entering the deflection plates? What quantities will you hold constant for this measurement? How many measurements do you need? Complete your measurement plan.

<b>MEASUREMENT</b>
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Measure the position of the beam spot as you change the initial velocity of the electron entering the deflection plates.

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

<b>ANALYSIS</b>
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Draw a graph of your Prediction equation for the deflection of the electron beam as a function of the initial electron velocity.

On the same graph, draw your measurements of the deflection of the electron beam as a function of the initial electron velocity.

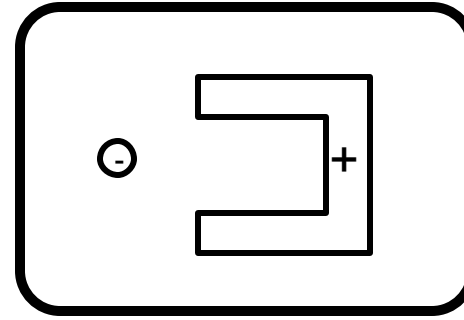
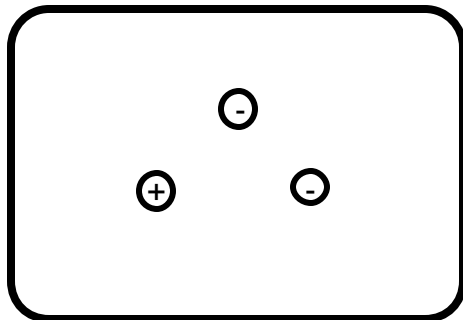
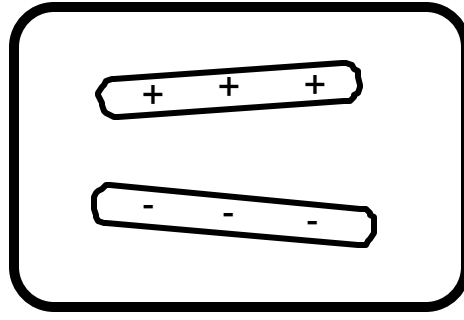
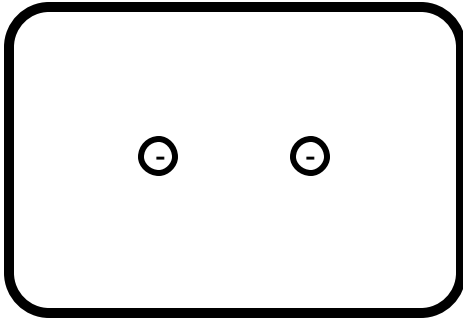
**CONCLUSION**

How does the graph based on your data compare to the graph based on your prediction? 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.

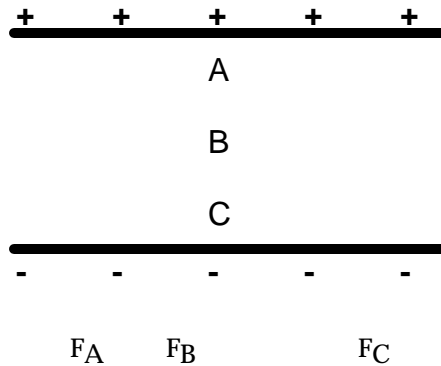
Did your data agree with your prediction of how the electron beam would deflect due to the initial electron velocity? Why or why not?

## ☑ 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  $V_x$  plate to the fluorescent screen is 10 cm and the distance from the center of the  $V_y$  plate to the screen is 8 cm. If  $V_{acc}$  is 300V,  $V_x = -8V$  and  $V_y = 3V$ , 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 1102 LABORATORY REPORT

### Laboratory IV

Name and ID#: \_\_\_\_\_

Date performed: \_\_\_\_\_ Day/Time section meets: \_\_\_\_\_

Lab Partners' Names: \_\_\_\_\_

\_\_\_\_\_

Problem # and Title: \_\_\_\_\_

Lab Instructor's Initials: \_\_\_\_\_

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

