Name ________________________________

Partner(s): ________________________________

Experiment 2 – Deflection of Electrons

Objectives To study the effects of electric fields on beams of fast moving electrons.

Equipment Cathode-ray tube (CRT), voltage divider board, 50-volt source

Preparation You will be pressed for time during the lab. Since successful completion of all lab activities counts towards your final lab grade it will be important to be well prepared by doing Pre-Lab assignments and reading the entire lab **before** attending the lab.

Pre-Lab Read the Pre-Lab introduction and answer the accompanying questions and problems **before** this Lab.

Points earned today

Pre-Lab	____
Lab	____
Total	____
Instructor Initials	____
Date	____

Pre-Lab for LAB 2

Introduction: A schematic drawing of the CRT is shown in Figure 1. The picture tubes used for old television and computer screens are just more highly evolved versions of the cathode ray tube (CRT). The significant feature of these devices is a beam of electrons, which travels at high speed through a vacuum in a glass container. The electrons are obtained by "boiling" them off a cathode, which is heated to a high temperature by a filament similar to the ones in light bulbs. They are then accelerated (from left to right in Figure 1) through a potential difference V_a of several hundred volts, and are focused into a beam by the electron gun (Region I of Figure 1.)

CRT's without their glass container are available in the lab for you to examine.

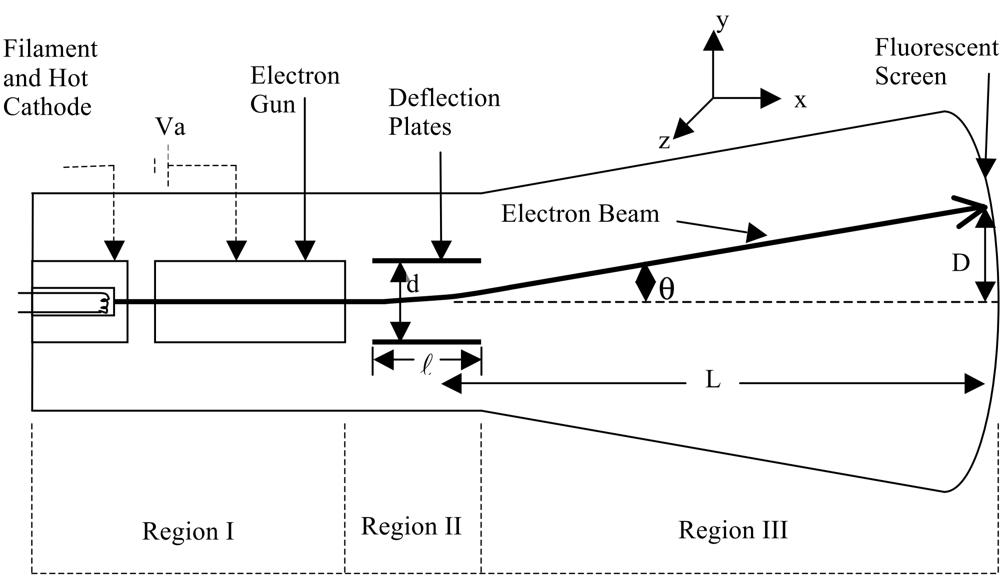


Figure 1. Schematic drawing of a cathode-ray tube

The speed of the electrons can be found by using the principle of conservation of energy. Assume that the electrons start out with nearly zero speed; then their kinetic energy after leaving Region I is

$$\text{(Final KE)} = \frac{1}{2}mv^2 = \text{(Initial Potential Energy)} = qV_a = eV_a,$$

where e is the charge and m the mass of an electron. This equation can be rearranged for the final velocity of the electrons as they leave Region I,

$$v_x = v = \sqrt{\frac{2eV_a}{m}}.$$

The electrons are moving horizontally as they leave the gun. Therefore the horizontal velocity component is $v_x = v$, and the vertical velocity component is $v_y = 0$. If no forces are exerted on the electrons in Regions II or III, they travel in a straight line and strike the fluorescent glass screen near the center, producing a small glowing spot. (The force of gravity has a negligible effect on the electrons over this short distance.)

Pre-Lab for LAB 2

However, if other forces do act on the electrons in either of these regions, the beam will be deflected from its original path. In this lab you will introduce an electric field (in Region II), which will produce a force on the electrons. The electric field will be produced by applying a voltage to the deflection plates (see Figure 1, Region II).

For the calculations in this lab, you will need to know some of the dimensions inside the CRT. The following are average values; the variation from one tube to another seems to be about ± 15%.

Length of vertical deflection plates, $\ell = 0.018$ m
Distance between vertical deflection plates, $d = 0.0025$ m
Distance from vertical deflection plates to screen, $L = 0.16$ m
Also, the accelerating voltage V_a for your CRT is written on the front of the wood housing. A typical value is $V_a = 550$ volts.

Other useful information:
charge of the electron: $q = e = 1.60 \times 10^{-19}$ C
mass of the electron: $m = 9.11 \times 10^{-31}$ kg

Problems:

1. If the accelerating voltage V_a is 250 volts, what is the speed of the electrons emerging from the gun?

2. Using the speed of the electrons you found in Problem 1 above, compute the time required for an electron to travel the 0.16 meter distance from the deflection plates to the screen. Then compute the deflection caused by gravity acting on the electron over this distance.

☐ Have your instructor check your work.

Laboratory

Activity 1: Using an <u>Electric Field</u> to deflect the Electron Beam in the CRT.

1. Set up the CRT. Disconnect all the wiring from the previous lab, if any. Set the intensity knob on the CRT housing to midrange. Plug in the CRT power cord. Allow 30 seconds for warm-up, then adjust the intensity of the green spot to be easily visible but not blindingly bright. (You could damage the phosphor coating of the CRT screen.)

2. Information on Electric Deflection of the beam. If a voltage V_p is applied to the vertical deflection plates in Region II, a nearly uniform electric field E_y is set up, which points in the y-direction. The magnitude of this field is $E_y = V_p/d$, where d is the distance between the plates. This electric field exerts a vertical force of magnitude $F_y = eE_y$ on each electron, resulting in a vertical acceleration $a_y = F_y/m$, by Newton's 2nd Law. There are no horizontal forces or accelerations in this region.

The time during which this vertical force acts is the time each electron spends passing between the plates. This time t depends on how fast the electrons are moving horizontally, and on the length ℓ of the plates: $t = \ell/v_x$. During this brief time, the electrons acquire a small vertical component of velocity $v_y = a_y t = a_y(\ell/v_x)$.

Because of this acquired vertical velocity component, due to the applied voltage V_p, the electrons are no longer traveling horizontally when they leave Region II. They have been deflected through an angle θ, where $\tan\theta = v_y/v_x$.

There are no significant forces on electrons in Region III, so the beam travels in a straight line in its new direction until it covers the horizontal distance L between the plates and the screen. It strikes the screen, displaced a vertical distance
$D_y = L \tan\theta$ from where it would have hit if there were no deflection voltage V_p on the plates. In a real CRT there are two pairs of deflection plates; the second pair deflects the beam horizontally on the screen. You will not be using these horizontal deflection plates in this experiment. Connect together the two horizontal deflection terminals on the top of the wooden housing. (They may be marked with an "H".) Use a very short wire or paper clip if possible. Since you will not be using these plates, you want to connect them together to remove possible annoying stray signals.

3. Build the circuit shown in Figure 2. The circuit contains a voltage divider (potentiometer) for applying a variable voltage V_p to the vertical deflection plates (these may be marked with a "V" on the CRT). The voltmeter is a digital multimeter, with its rotary switch set to measure DC voltages.

   The circuit may have been already set up for you. If so, please examine it and see if you can follow how the real circuit corresponds to the circuit diagram. A knob adjusts the variable resistor.

   Initially, adjust the knob on the variable resistor until the voltage reading V_p is about zero – you may not be able to adjust the voltage to exactly zero. Adjust the CRT focus for the sharpest spot, or for the sharpest horizontal line if you can't get a point spot. Since you will be measuring vertical deflections, you want the vertical fuzziness of the spot to be as small as possible.

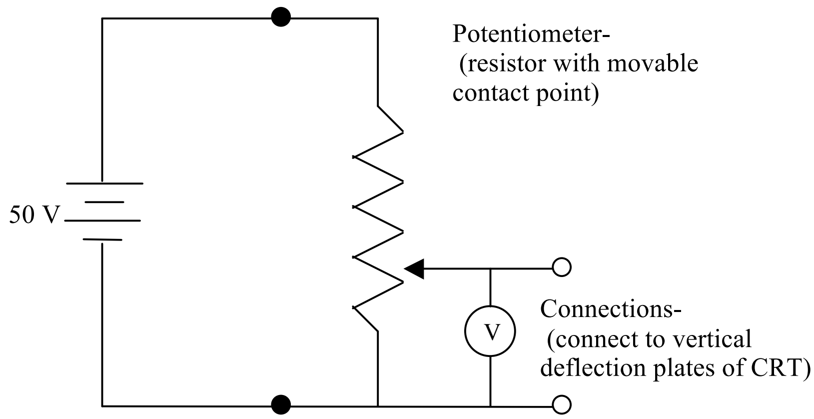


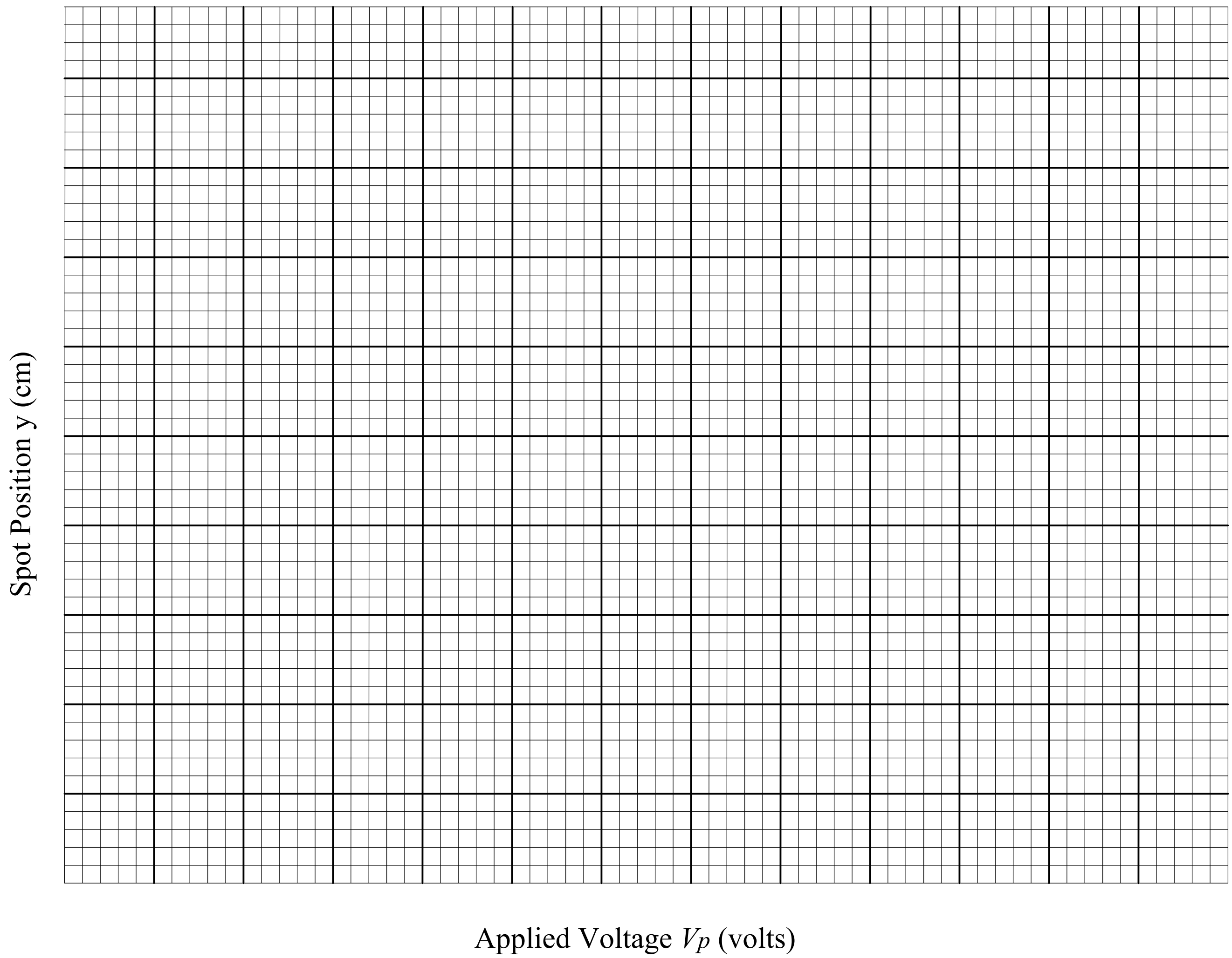
Figure 2. Voltage divide circuit for supplying electric deflection voltage V_p.

4. <u>Take and record data for spot position y vs. applied deflection voltage V_p.</u> Take data for about seven values of y in one centimeter steps (where convenient) so that the voltage V_p varies from about -30 volts to +30 volts or so, depending on the apparatus. You will find it convenient to adjust the voltage to values that will allow you to read the position y of the spot easily. If the voltage is too large, your spot may move off screen, so adjust the voltage in order to get smaller increments for y. How do you change the sign of the applied voltage?

y (cm)	V_p (volts)

☐ Have your instructor check your progress at this point.

5. Plot a graph of your data, with V_p on the x-axis. Draw the "best fit" straight line through your data.



Graph 1. Deflection due to an Applied Voltage.

6. Find the slope of the graph. Show your work, and <u>include units</u> in your final answer. What is the significance of the slope?

☐ Have your instructor check your progress at this point.

7. Calculate the Electric Deflection. Calculate the expected value of this deflection D_y, making use of the accelerating voltage V_a and the dimensions of the CRT, by following the steps below. You may wish to refer to the discussion on pages II-1 and 2, and on page II-4.

Useful information: charge of the electron: $q = e = 1.60 \times 10^{-19}$ C mass of the electron: $m = 9.11 \times 10^{-31}$ kg

A. If an electron starts from rest at the cathode and is accelerated by this V_a in the electron gun, what is its horizontal velocity $v=v_x$ when it emerges from the gun? Show your work below.

Copy down V_a: V_a = _______ volts

Use: $PE_1 + KE_1 = PE_2 + KE_2 \rightarrow qV_a + 0 = 0 + \frac{1}{2}mv^2$

B. The vertical deflection plates of the CRT have a length $\ell = 0.018$ m in the direction the electrons are moving. How much time Δt does each electron spend between the plates? Show your work and equations below.

C. These deflection plates are a vertical distance $d = 0.0025$ m apart. If the deflection voltage were 1.0 volts, what would be the vertical electric field E_y between the plates? What would be the vertical force F_y on an electron due to this electric field, and the acceleration a_y resulting from this force? Show your work below.

$E_y =$

$F_y =$

$a_y =$

D. Each electron passing through the deflection plates feels the electric force for a time Δt, which you calculated above. What are the resulting vertical velocity v_y and deflection angle θ? Show your work and equations below.

$v_y =$ $tan\ \theta =$ $\theta =$

E. This deflection angle occurs at a distance $L = 0.16$ m from the screen. What is the resulting vertical deflection $D_y = \Delta y$ at the screen for $V_y = 1.0$ volt? Show work below, including a sketch.

F. Compare with the measured deflection per volt and calculate the relative error for your measured value, in %: [(measured – calculated) / calculated] × 100.

G. a) What do you think could account for this error? Be specific.

b) Why not just measure one data point with $V_p = 1.0$ volts for Activity 1?

a)____

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b)____

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☐ **Stop. Have your instructor check your progress and that your worktable is cleaned up before you leave the lab room.**