

## THE OPERATION OF A CATHODE RAY TUBE

**OBJECT:** To acquaint the student with the operation of a cathode ray tube, and to study the effect of varying potential differences on accelerated electrons.

**THEORY:** A heater coil in the back of the CRT, when supplied with 5 to 6.3 volts AC, heats the cathode which in turn emits a high density electron stream. The electrons pass through an aperture and are focused into a beam. They enter an axial electric field ( $E_a$ ) and are uniformly accelerated in the axial direction by an accelerating potential ( $V_a$ ). The resulting axial velocity ( $v_x$ ) can be calculated using the conservation of energy equation:

$$\Delta KE = \Delta PE, \text{ or } \frac{1}{2} m_e v_x^2 = e V_a, \text{ or } v_x = [2 e V_a / m_e]^{1/2} . \quad (1)$$

After the electrons leave  $E_a$  they continue at the constant velocity ( $v_x$ ) until they reach the deflecting plates. If an electric field ( $E_d$ ) exists between the deflection plates due to an applied voltage difference ( $V_d$ ), the electrons are accelerated (deflected) toward the more positive plate and they acquire a velocity ( $v_y$ ) perpendicular to the plates. The force exerted on an electron due to the deflecting field is  $F_E = e E_d$ . As this force acts for a time  $t_1$ , then the speed  $v_y$  can be found:

$$v_y = a t_1, \text{ where } a = F_E / m_e = e E_d / m_e .$$

Therefore,

$$v_y = e E_d t_1 / m_e . \quad (2)$$

Since the electric field strength,  $E_d$ , is constant between parallel plates,

$$V_d = E_d d, \text{ or } E_d = V_d / d \quad (3)$$

where  $d$  is the separation of the two parallel deflecting plates. The time they are in the field is related to the plate length ( $s$ ) by

$$v_x = s / t_1, \text{ or } t_1 = s / v_x . \quad (4)$$

Therefore, from Eqs. (2), (3), & (4) :

$$v_y = e (V_d / d) (s / v_x) / m_e, \text{ or } v_y = (e V_d s) / (m_e v_x d). \quad (5)$$

Having been affected by the voltages  $V_a$  and  $V_d$ , the electrons are deflected at an angle  $\theta$  with respect to the tube axis where  $\theta$  can be determined from

$$\tan(\theta) = \text{Opposite side/Adjacent side} = D/L \quad (6)$$

where  $D$  is the deflection distance on the screen and  $L$  is the distance from the midpoint of the parallel plates to screen.

The velocities are proportional to the lengths, because the time interval is the same; thus

$$\tan(\theta) = v_y / v_x = D/L . \quad (7)$$

Using Eq. (1) and Eq. (5) we can get the ratio of velocities in terms of the voltages:

$$v_y/v_x = (V_d s)/(2dV_a) . \quad (8)$$

Finally, then, using Eq. (8) in Eq. (7) we get:

$$D/L = \tan(\theta) = v_y/v_x = (V_d s)/(2dV_a), \quad \text{or} \quad D = (V_d sL)/(2dV_a) \quad (9)$$

The electrons then continue at constant velocity in a straight line until they strike the screen and activate the phosphorescent coating on the inside, causing it to glow. Note: in this experiment **we are going to test Eq.(9)**. Note that  $s$ ,  $L$  and  $d$  all depend on the shape of the CRT and can't be changed. Only  $V_d$  and  $V_a$  can be varied in this experiment.

## Part 1: Electric Fields and Voltages

### POWER SUPPLY WIRE CONNECTIONS:

**DO NOT CONNECT ANY POWER CORDS YET.** Coming out of the back of the CRT are three sets of wires. One set contains six color coded wires that produce the electron beam. The other two sets each contain two wires that control the vertical and horizontal deflection of the beam. All of the wires terminate inside the connection box. A wiring diagram appears on the last page. You may wish to refer to it as you make the connections with the banana plug wires.

*Connections for the heater coil:* With the tube high voltage supply turned off and unplugged, connect two wires from the yellow ac voltage outputs on the tube supply to the yellow terminals marked "Filament" on the connection box. Set the ac voltage knob on the supply to 6 V.

*Connections for the accelerating plates:* With the tube high voltage supply turned off and unplugged, connect the 500 V output on the tube supply to the red A terminal of the  $V_a$  inputs on the connection box. Connect the 0 V output on the tube supply to the black B terminal of the  $V_a$  inputs on the connection box. With another wire, connect the red A terminal of the  $V_a$  inputs to one of the green ground inputs on the connection box.

*Connections for the deflection plates:* With the variable dc voltage supply turned off and unplugged, connect the + and - outputs of the supply to the vertical deflection terminals on the connection box with two wires. It doesn't matter which plate is positive or negative. Connect the negative terminal of the supply to the ground terminal (middle terminal) of the supply. With another wire, connect this ground terminal to one of the green ground inputs on the connection box. Connect the horizontal deflection terminals on the connection box to the green ground terminals on the box. Finally, connect a DMM to the + and - terminals of the supply to measure the deflection voltage difference,  $V_d$ . The CRT is now set up for vertical deflection of the electron beam.

Once you have completed the wiring, **ask your instructor to check it before you plug in the power supplies.**

**PROCEDURE :**

1. Make sure that the high voltage control is turned all the way down ( $V_a = 0$ ) and turn on the HV supply. Allow the heater coil to warm up. You should see the coil glowing in the back of your CRT. Now increase the high voltage to 500 V. Use the meter on the HV supply to read the voltage difference. Varying the potentiometer control on the connection box changes its resistance which changes how the accelerating voltage difference  $V_a$  is split between the accelerating plates of the CRT. This will affect the collimation of the electron beam. Turn the pot control to obtain the best focus of the dot. (Referring to the CRT wiring diagram, the potentiometer is in series with a fixed resistor which forms a voltage divider. The voltage difference across the pot is  $V_b$ , that across the fixed resistor is  $V_c$ , and the sum of these gives the total accelerating voltage difference  $V_a$ .)
2. Rotate the CRT horizontally (in the plane of the table) until the dot is at a convenient starting position. Record its position. (This is with  $V_d = 0$ ). When reading the CRT, put your eye so that the dot, your eye, and your eye's reflection are in the same line.
3. Now turn on the variable dc voltage supply and take readings as you vary  $V_d$  from zero to its maximum value or until the dot goes outside the grid. (**A good place to record the voltage is at every  $\frac{1}{4}$  inch grid mark.**) Make the position of the dot at  $V_d = 0$  correspond to  $D = 0$ .
4. Now reverse the deflection plate terminals with respect to the variable voltage supply and again take readings as you vary  $V_d$  from zero to its maximum value or until the dot goes outside the grid.
5. Decrease  $V_a$  to 400 V and repeat the procedure in step 3 in order to get a second set of data for deflection in one direction. You do not have to reverse the deflection plate terminals as in step 4. However, use the deflection plate connections which allow the largest deflection voltage to be used.
6. Decrease  $V_a$  to 300 V and repeat the procedure in step 5 in order to obtain a third set of data.

**REPORT:**

1. Graph the following two relationships:
  - A.  $D$  vs  $V_d$  (3 straight lines with different slopes on one graph) [\* See note on last page.]
  - B.  $V_a * D$  vs  $V_d$  (again plot all 3 data sets on a second graph) and report the effective  $(sL/2d)$  value for the deflection plates (the slope).
2. What is the correlation between the slopes of the lines in 1A and the accelerating potential  $V_a$ ? What does theory (Eq. 9) say about how the slopes should depend on  $V_a$ ?
3. What does theory (Eq. 9) say the slopes of the three lines for graph 1 B should be? How well does your data support this prediction?

4. The following two explanations should be in words and should be based on basic laws and relations (such as Newton's 2nd Law, conservation of energy, and the definition of electric field). (a) Explain how and why changing the deflecting potential ( $V_d$ ) will affect the deflection of the electron beam. (b) Explain how and why changing the accelerating potential ( $V_a$ ) will affect the deflection of the electron beam.
5. Discuss sources of experimental uncertainty. Do these sources of experimental uncertainty account for any discrepancies between theory and the results of your experiment?

## Part 2: Magnetic Fields

### PROCEDURE:

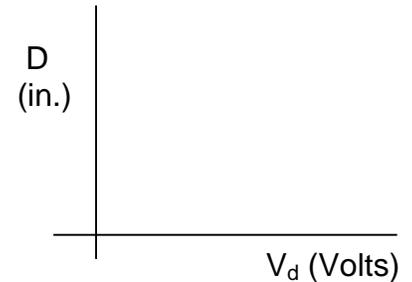
1. With  $V_d$  set at 0, take a bar magnet and hold it several feet away from the right side of the CRT. Point the bar magnet at the right side of the CRT and bring the magnet slowly closer to the CRT. Observe the deflection of the beam. Does the deflection of the beam depend on how near the front or back of the right side of the CRT you point the magnet?
2. Repeat the procedure with the opposite side of the magnet pointing toward the right side of the CRT.
3. Repeat on the left side.
4. Now hold the magnet several feet above the CRT and slowly bring the magnet toward the top of the CRT. Observe the deflection of the beam.
5. Again repeat the procedure with the opposite side of the magnet pointing toward the top of the CRT.
6. Now hold the magnet a foot or so below the CRT (i.e., under the desk). Does the desk shield the CRT from the magnet?
7. Finally, point the magnet directly at the beam and approach the beam carefully. Observe the deflection. When at the screen face, slowly move the magnet up (still pointing it parallel to the beam) and then to one side.

### REPORT:

1. Record your results for all parts above.
2. Can you devise a general rule that covers all of your observations?

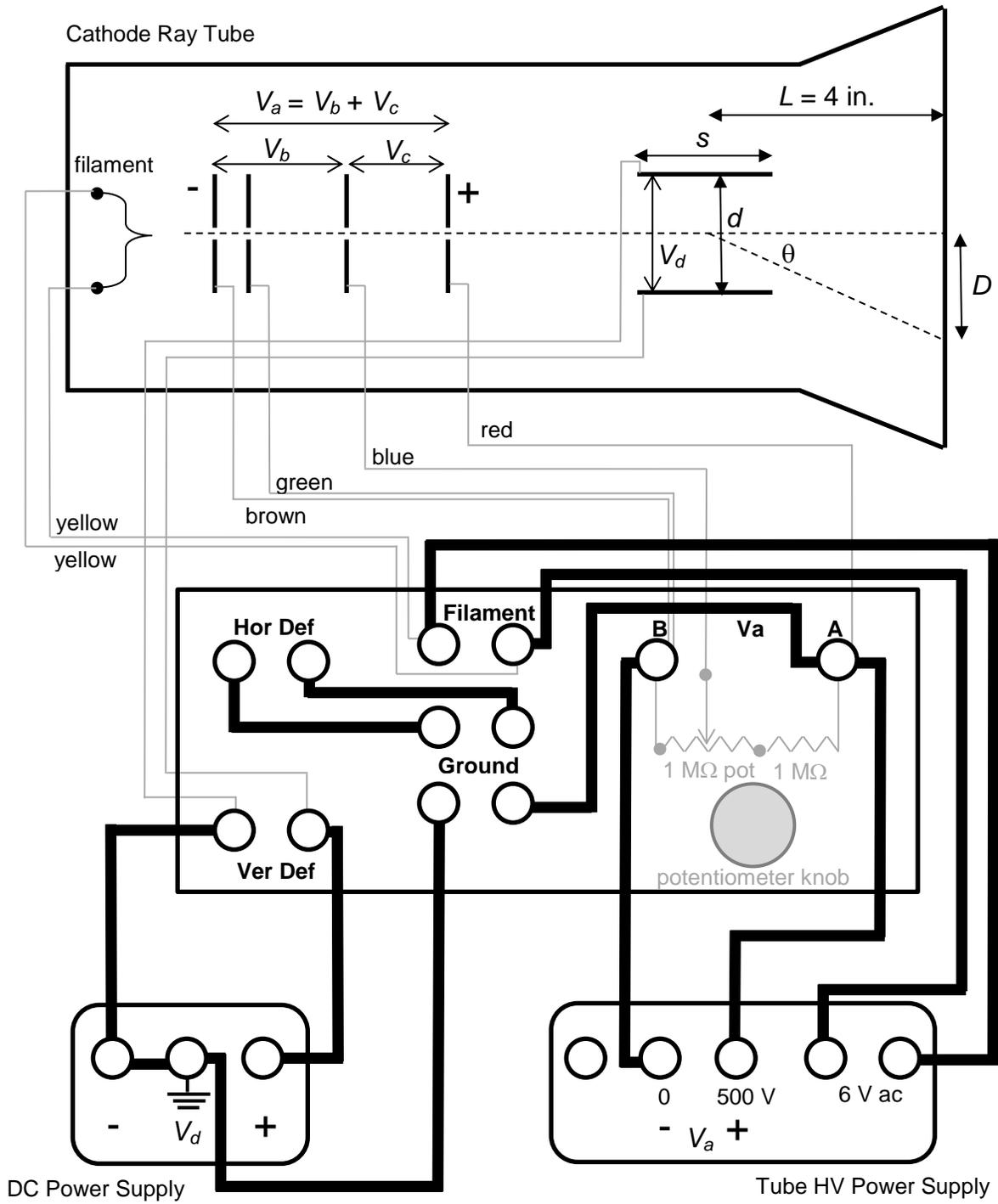
### Note on making graphs

We normally plot the independent variable on the horizontal axis (x), and the dependent variable on the vertical axis (y). For graph A, **the distance of deflection,  $D$ , depends on the deflecting voltage,  $V_d$** , so normally we would **plot  $D$  on the vertical axis and  $V_d$  on the horizontal**. From theory, we have Eq. 9:  $D = V_d (sL/2dV_a)$ , and this is what we are trying to check with our graphs.



If you measured the deflecting voltage for each  $\frac{1}{4}$  inch of deflection, so that you have different "x" values ( $V_d$ 's) for the same "y" values ( $D$ 's) in the three different runs, and if you have trouble with your plotting routines doing this, you may reverse the above graph and plot  $V_d$  vs  $D$ . This will allow you to have different "y" values ( $V_d$ 's) for the same "x" value ( $D$ ), and may make plotting your three runs on the same graph easier. However, **if you do this**, you should note this in your report and explain the reason for the change. Also, be aware that from Eq. 9, we see that the slope of the  $D$  vs  $V_d$  curve is  $(sL/2dV_a)$ , but the slope of the  $V_d$  vs  $D$  curve (flipping "y" and "x") gives the inverse slope of  $(2dV_a/sL)$ .

### CRT Wiring Diagram



— Permanent Existing Wire Connections

— Banana Plug Wire Connections