Instruction Manual

from

PSSC Physics Laboratory Guide

Seventh Edition

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EXPERIMENT 28

Deflecting Electrons in a Cathode Ray Tube

In a cathode ray tube (CRT), electrons travel in a narrow beam from the electron gun near the socket to the face of the tube. When they strike the coating on the inside of the face, light is emitted (Fig. 28—1). Partway along the tube the beam passes between two pairs of deflecting plates one after the other. They are called X and Y plates. When a potential difference is applied across the X plates, the beam is deflected horizontally. A potential difference across the Y plates deflects the beam vertically. The purpose of the experiment is to study these deflections as a function of the voltage applied to the X and Y plates.

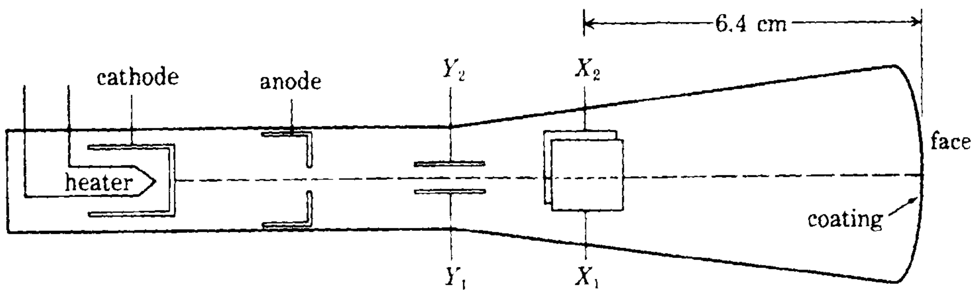

Figure 28—1 The key elements of a cathode ray tube. The focusing device is not shown.

The initial electric connections are shown in Fig. 28—2 on the next page.

CAUTION: Make all connections and changes in connections with the power supply off.

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- What accelerating voltage V_a will you get with these connections?

After you have checked the connections, plug in the power supply and turn it on. Adjust the focus knob of the CRT to make the light spot as small as possible. This will be the zero point from which deflections will be measured.

When you have a well-focused beam, you can connect the X plates to the ground and +8 V terminals (Fig. 28—3 on page 3) and measure the deflection of the beam. The grid is marked in mm. You can mark the position of the spot on the plastic grid with a felt pen (water soluble only!). Move the connecting wire from the +8 V outlet to the —8 V outlet and again measure the deflection.

- Are the deflections of equal magnitude?

- What will be the voltage between the X plates when you connect them to the +8 V and —8 V outlets?`

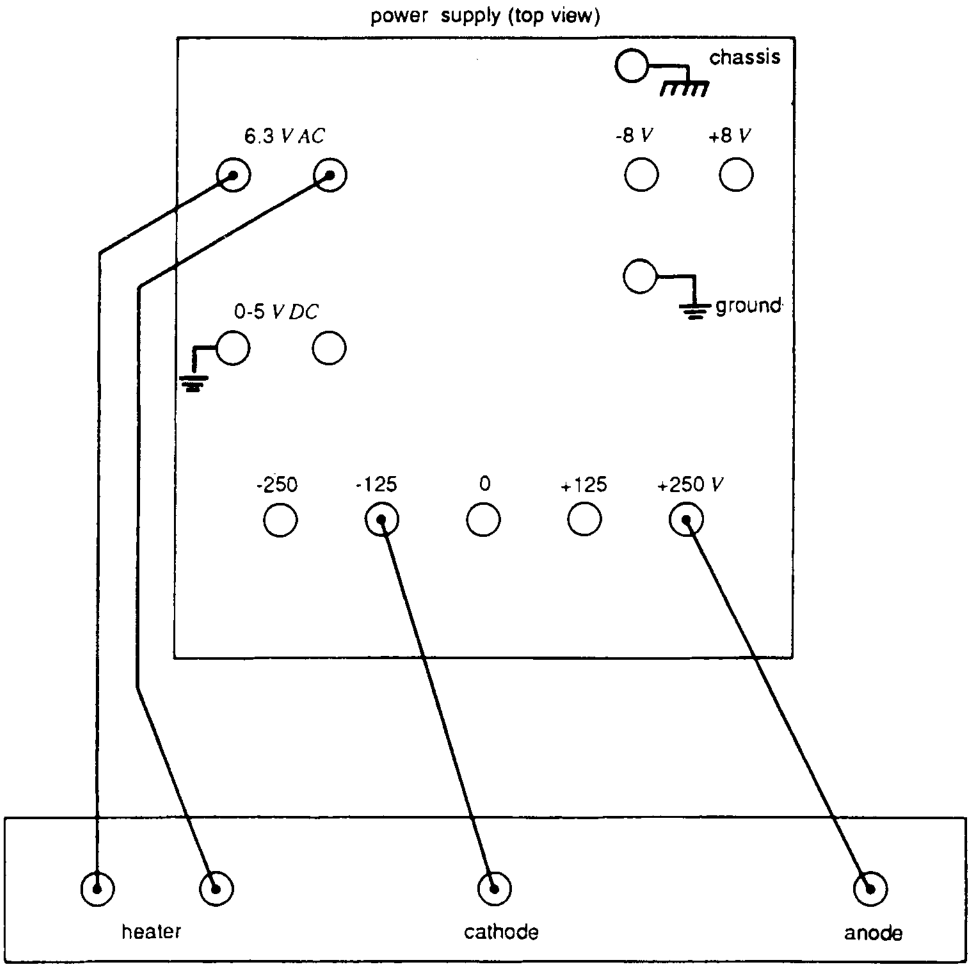

Figure 28-2a The initial connections between the base of the CRT and the power supply. Be sure your power supply has a floating 6.3 Vac outlet. Do not use a grounded outlet for the CRT heater.

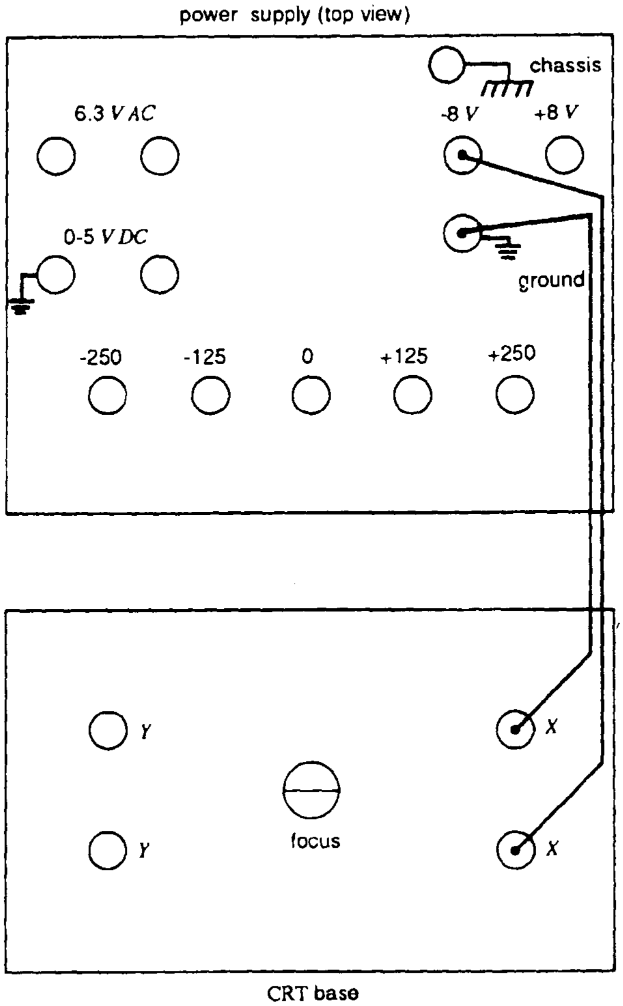

Figure 28-3a

Measure the deflections for this and the opposite configuration, and plot the deflection x as a function of the deflecting voltage V_d.

From your graph, is the deflection per volt the same in all cases?

In most applications of a CRT, one measures the deflection and uses it to determine the deflecting voltage. That is, the CRT serves as a very fast voltmeter. The voltage required to get a deflection of 1 cm is called the sensitivity S of the CRT.

CAUTION: Disconnect the wires at the power supply before shifting them from the X-connection to the Y-connection.

- Is the sensitivity of the CRT the same for horizontal and vertical deflections?

The X plates and the Y plates are identical in construction.

- Which deflection plates are closer to the face of the tube? How do you know?

Find the sensitivity of the CRT for both the x and y deflections. Do that for accelerating voltages of 500 V (connect the cathode to —250 V), and of 250 V (connect the cathode to 0 V).

- How does the sensitivity depend on the accelerating voltage?

EXPERIMENT 29

The Mass of the Electron

In this experiment you will calculate the mass of the electron from observations made on the motion of electrons in electric and magnetic fields. The electric field is produced by two charged plates inside the CRT, and the 'magnetic field by a coil. The trajectory of the electron is rather difficult to visualize in this case. Therefore, it is best to start with observations on the cathode ray tube and then proceed to the calculation.

An Air Core Solenoid which slips over the CRT enclosure produces the magnetic field along the axis of the tube. The solenoid is not supplied with the apparatus and must be purchased separately. The Sargent Welch CP72700-02 Air Core Solenoid or the Frey Scientific G01884 Solenoid Coil PSSC are satisfactory.

Start with an accelerating voltage of 250 V and neither coil nor Y-deflection plates connected to the power supply. Try to predict the answers to the following questions, and then check them. At each stage, mark the position of the light spot on the grid with a felt pen (washable ink only!). Record it also in your notebook.

- With no voltage on the deflecting plates, do the electrons hit the center of the face of the tube?

- Does the velocity of the electrons have a small component perpendicular to the axis of the tube?

- Where do the electrons hit if the Y plates are not connected but the current in the coil is gradually increased from zero? Why? (Start with the control knob of the DC voltage turned all the way counterclockwise, and gradually turn it clockwise.)

- Where will the electrons hit if there is no current in the coil and a voltage across the *Y* plates, with the top Y plate positive? (Disconnect the coil to be sure no residual current gets through.)

- How will the point where the electrons strike the face of the tube change when the current in the coil is gradually increased from zero and there is a constant voltage across the *Y* plates?

- Is there a specific current in the coil, I_1 for which the line makes a right angle with the line for no current as in Fig. 29—2? If so, measure this current.

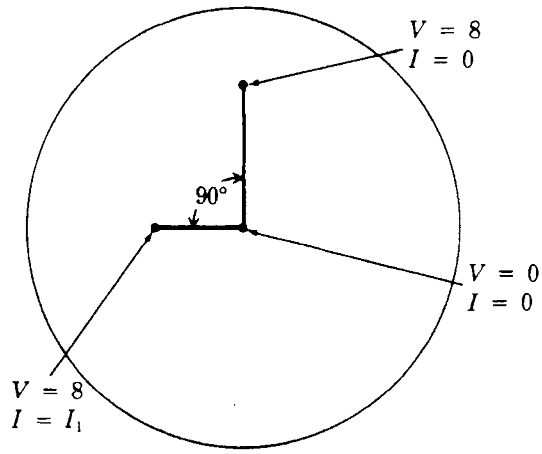

Figure 29-2

Let us now analyze the motion of the electrons under the applied voltage and current. As the electrons enter the magnetic field, the component of their velocity along the axis of the tube is

$$v_a = \sqrt{2eV_a/m} \qquad (1)$$

where V_a is the accelerating voltage and e and m are the charge and mass of the electron, respectively.

- How was Equation (1) derived?
- What is the value of V_a in your experiment?

The voltage across the Y plates initially gave the electrons a velocity in the Y direction. The magnetic field turned this velocity around through 180° by the time the electrons reached the face of the tube (Fig. 29—3 on the next page). In the XY plane the electrons moved along a semicircle of radius r with a speed v_t given by

$$v_t = e\,B\,r/m \quad (2)$$

- From the results of the preceding experiment, what is the value of B when the current I_1 passes through the coil?

The magnetic field produced by a given current was measured in an earlier experiment. Typically solenoid produces 3 mT / A. at the center of the coil. The units of the magnetic field are milliTeslas while the current is in amperes.

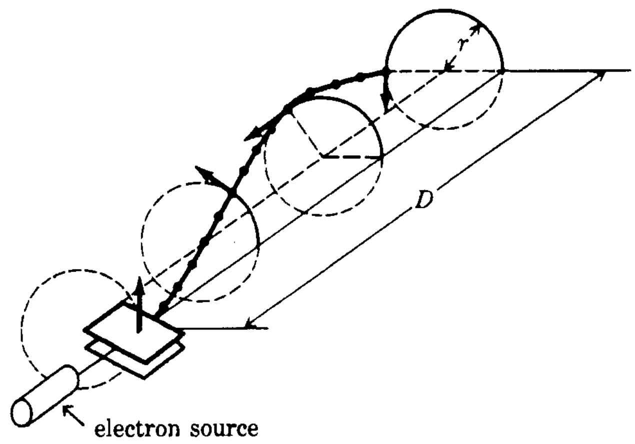

Figure 29—3 Schematic drawing of the trajectory of the electron under the influence of an electric and a magnetic force. Starting from the lower left, v_t is initially up. The magnetic field along the axis of the coil turns the electrons counterclockwise while they move along the tube with a velocity v_0.

The time it took the electrons to move from the center point between the Y plates along the axis of the tube a distance D to the face of the tube is the same as the time it took to complete the semicircle. In both cases the time is given by distance divided by speed:

$$\text{(time along axis) } D/v_0 = \pi\, r/v_t \text{ (time along semicircle)} \qquad (3)$$

Substituting v_0 from Equation (1) and v_t from Equation (2) into Equation (3) and solving for m yields

$$m = e\, B^2\, D^2 / 2\, \pi^2\, V_a \qquad (4)$$

According to the manufacturer, D = 9.0 cm. However, there may be small variations from tube to tube.

- With this value of D and the values of your measurements, what is the mass of the electron?

If our reasoning is correct, the mass calculated from Equation (4) should be independent of V_a and B within experimental errors. Repeat the experiment with $V_a = 375$ V and $V_a = 500$ V.

- What do you find?

EXPERIMENT 30

The Magnetic Field of the Earth

The cathode ray tube which you used in Experiments 28 and 29 does not have a control that enables you to center the light spot on the tube's face. Indeed, you may have noticed that even without your providing a deflecting force, the electrons did not strike the center of the face. Is this effect due entirely to the construction of the tube, or is it possible that there is also an external factor?

To find out, connect the CRT to the power supply with the anode set at +250 V, the cathode at 0 V, and the heater at 6.3 V AC.

CAUTION: Make all connections with the power supply *OFF*.

- What happens to the light spot when you lift the tube from its base and change its orientation in space? Try rotating the tube around its own axis and perpendicular to its axis.
- Is there an external force acting on the electrons?
- From your observations, is the external force an electric force or a magnetic force? Why?

Suppose that you hold the CRT so that the electrons move parallel to the magnetic field of the earth. Then the magnetic field will not affect their motion. Except for the short distance between the cathode and the anode, the electrons will move in a straight line with a velocity

$$v_a = \sqrt{2eV_a/m} \qquad (1)$$

where V_a is the accelerating voltage and e and m are the charge and mass of the electron, respectively.

Suppose that you now turn the CRT so that v_o is perpendicular to the magnetic field of the earth, B_{earth} (see Fig. 30—1). Then the electrons will be deflected sideways with a force of magnitude

$$F = e\, v_o\, B_{earth}$$

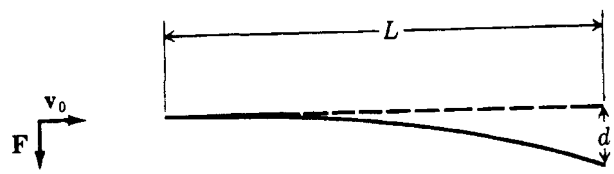

Figure 30—1 With v_o pointing to the right, and B_{earth} perpendicular to the plane of the paper and pointing into it, the deflecting force will be downward, as shown.

As long as the electrons change their direction of motion very slightly, we can ignore the resulting change in the direction of the deflecting force and consider this force to be constant in direction and magnitude. In this approximation the deflection of the electrons at the face of the tube will be

$$d = a\,t^2 / 2 \qquad (2)$$

where

$$a = F/m = e\, v_o\, B_{earth} / m \qquad (3)$$

and

$$t = L / v_o \qquad (4)$$

The distance L is close to the distance between the anode and the face of the CRT. Substituting a and t from Equations (3) and (4) into Equation (2), we have

$$d = e\, L^2\, B_{earth} / 2\, m\, v_o \qquad (5)$$

Substituting v_o from Equation (1) into Equation (5) and solving for B_{earth} yields

$$B_{earth} = (2d / L^2)\, \sqrt{2\, m\, V_a / e} \qquad (6)$$

You already know the values of m and e. For your CRT, L = 11 cm. The only quantity you have to measure is the deflection d, due to the magnetic field of the earth. For that you have to mark the positions of the light spot when the beam is parallel to the magnetic field, and when it is perpendicular to the field. Then d is the distance between the marks.

The problem is to find the direction of the magnetic field. You can do that in the following way. First hold the CRT more or less in the east-west direction on the laboratory table. Rotate the tube around its axis through a small angle and have your partner mark the position of the light spot on the grid with a felt pen (washable ink only!). Continue rotating and marking the positions through a complete turn.

- Why is it useful to hold the tube in an east-west direction?

- Do the points marked with the felt pen form a circle? If not, try again and be sure not to change the tube direction while rotating it around its axis.

Mark the center of the circle and change the direction of the CRT until the electrons strike at the center of the circle.

A compass will give you the direction of the horizontal component of the field. But most compasses will not work when held vertically; thus they will not help you find the direction of the field in the vertical plane.

- How can you convince yourself that the CRT is now lined up with the magnetic field of the earth? Try it.

For the magnetic field of the earth to produce the deflection d, which we calculated, the CRT can point in any direction in the plane perpendicular to the direction of the field. Thus, you can put the CRT on the laboratory table in a direction perpendicular to the magnetic field (Figure 30-2).

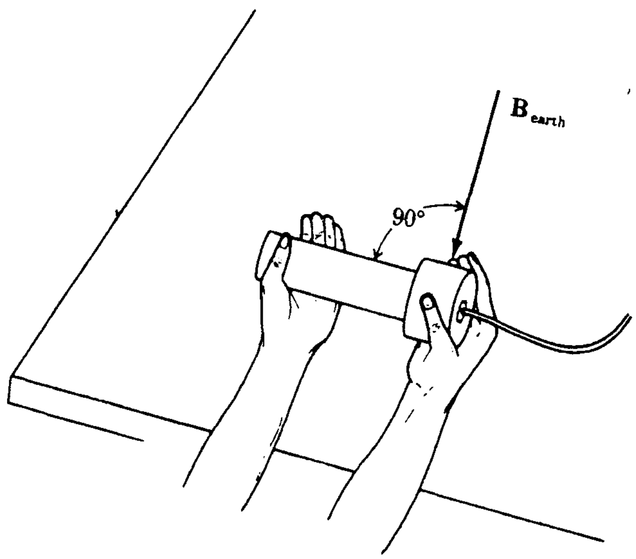

Figure 30-2

Mark the location of the light spot on the grid. The distance between this point and the center of the circle gives the value of d in Equation (6).

- What do you find for B_{earth}?

If our reasoning is correct, the value of B_{earth} should be independent of the values of d and V_a, within experimental errors. Repeat the experiment with V_a = 375 V.

- What do you find?