

EXPERIMENT 2: MOTION OF ELECTRON IN E-M FIELDS

In experiment 1 we studied ways to portray and visualize electromagnetic fields. Once we know the details of these fields, the next question is to examine their effects on charges present in these fields. One way to do this is to use electrons traveling in a cathode ray tube (CRT), and observe how they are deflected by the fields.

BACKGROUND

The electric field will be supplied by two sets of parallel plates at right angles to each other, and parallel to the electron's undeflected path. See diagrams on next two pages. One set of plates provides a horizontal electric field (and a horizontal deflection), and the other provides a vertical electric field (and vertical deflection) to the electron. (See figure on next page.) The electric field on the plates is caused by applying voltage to the plates, which will cause charges to stack up on the plates. The intensity of the electric field is proportional to the voltage applied to the plates, as we will see in the next few chapters of the text. The voltage is controlled by a power supply or power amplifier with adjustable voltage.

The magnetic field is supplied by two coils, placed on either side of the CRT, with the axes of the coils perpendicular to the axis of the CRT. In a second case one of the coils will be placed around the CRT, so the coil is coaxial with the CRT. The strength of the magnetic field is controlled by the amount of current through the coils. An important item to note, which we will study later, is that the magnetic field is roughly along the axes of the current carrying coils. The strength of the magnetic field depends on the size of the current in the coils. The force on the electron moving in a magnetic field is proportional to the strength of the field.

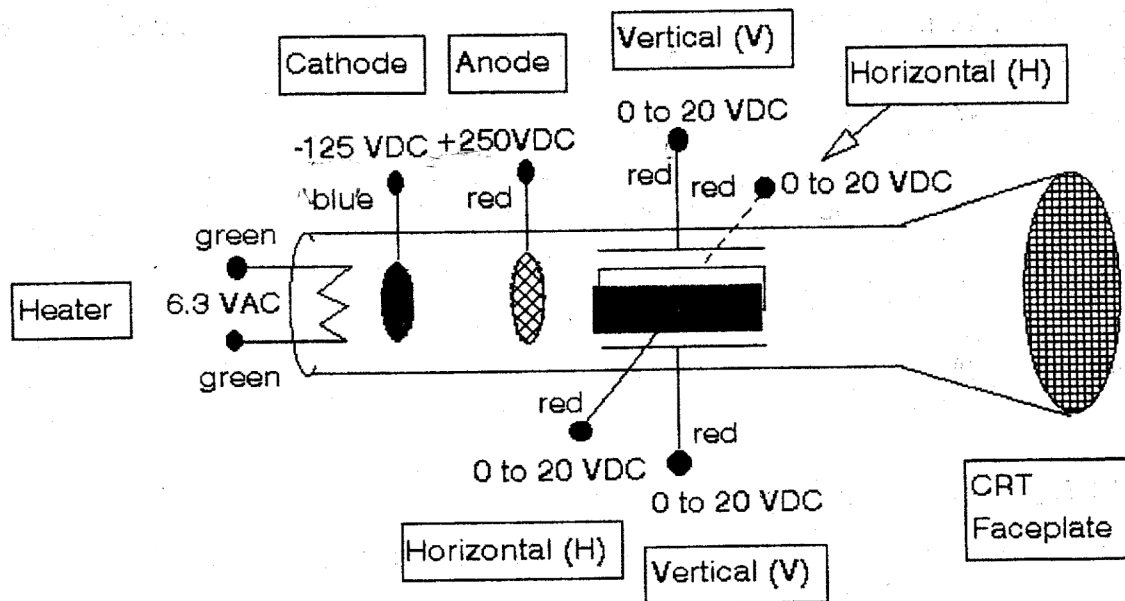
ADVANCE STUDY ASSIGNMENT

1. Based on information in the Background section, what should a graph of deflection of the electron vs applied voltage to the deflecting plates show the shape of the curve to be? Explain your reasoning.
2. The same reasoning does not (yet) apply to the motion of the electron in a magnetic field, again, based on information in the Background section. Why? (Hint: note that the statements in the Background section are not symmetrical in the electric and magnetic field cases, although in fact that might have been possible.)

PROCEDURE A

1. Connect the CRT to the power supply (the self-contained power supply, either in a beige case or in a blue metal case with stainless steel surface). Match the cables from the CRT to the power supply using the color-coded connection details shown on the accompanying figure on the next page. Do not turn on or plug in the power supply yet.
2. Turn on the Pasco interface and then the computer. Click on the Data Studio icon, and then click on "Create an Experiment". Next scroll down and double-click on Power Amplifier (in Experiment Setup window).

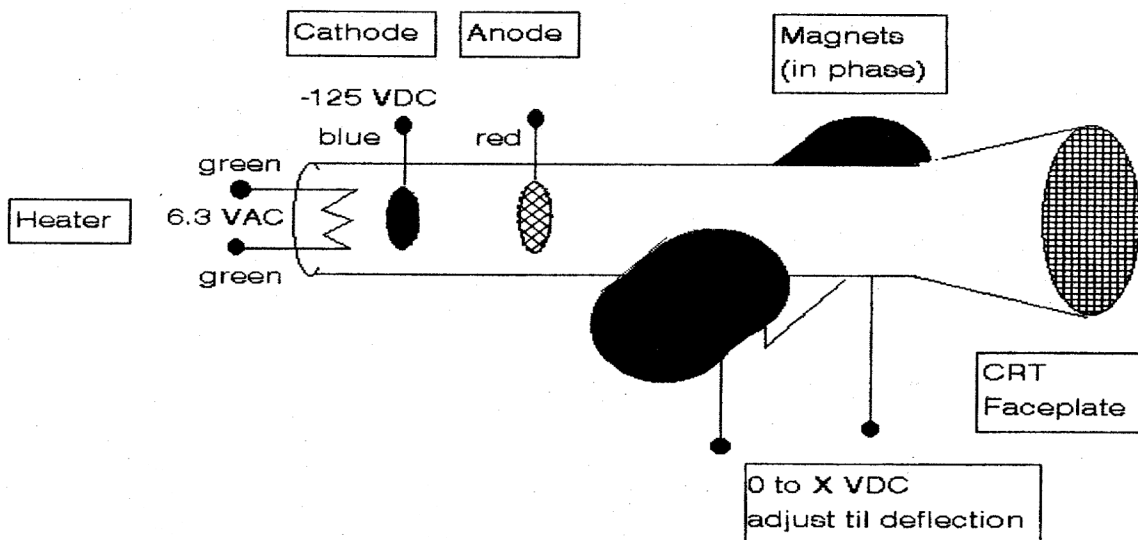
- On the Signal Generator control window (pops up after double-clicking on power amplifier in Experiment Setup window), make sure the generator is selected on “DC Voltage” and set the voltage to -5V by clicking on the arrow next to the voltage readout. Do not turn on or plug in the Power Amplifier yet.
- Connect the Power Amplifier to the horizontal deflection plates by using banana plug wires, black for negative and red for positive.
- When you have made all the connections, ask the instructor to inspect your CRT and Power Amplifier connections. After it is approved, turn on the CRT power supply and wait for the tubes (if you are using one of the older beige power supplies) to warm up. Make sure the standby switch is turned to DC. Before turning on the Power Amplifier, make sure you see a dot on the CRT. It may be necessary to adjust the focus button on the CRT, or to adjust the two DC voltage supplies. Both should be near the upper end of their ranges. Work with all three controls to get the smallest dot possible for the electron beam on the CRT faceplate.



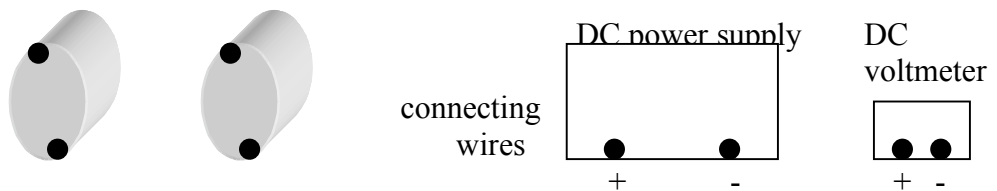
- Now make sure the Power Amplifier control window is active. If it is active, the bar at the top will be blue. If it is not active, click anywhere in the window. Next click the on button of the Power Amplifier control window, and watch the electron beam dot as you do so. You should see the beam jump as the Power Amplifier is turned on (to -5V if you followed the directions above).
- Rotate the CRT around its long axis so that the direction of motion of the electron beam is indeed horizontal. To do this, you may want to click the Power Amplifier on and off, to see the direction of the deflection.
- Now turn the Power Amplifier to 0V and record the horizontal position of the beam. Record the reading in Data Table A. Next adjust the voltage from -5V to $+10\text{V}$ in steps of 1V , and record the position of the beam for each voltage.

PROCEDURE B

9. Disconnect the Power Amplifier from the deflecting plates. Place the two large coils on either side of the CRT, as shown below. It may be helpful to place books or blocks of wood under the coils, so their common axis passes perpendicularly through the axis of the CRT. (It does not matter if the CRT is horizontal, or tilted in its stand.)



10. Connect the magnets in series, and in phase to a DC power supply. (In phase means the coils should be placed symmetrically, with both connecting posts in the same orientation. Be sure the coils are a matched pair, with the same color wires to the connecting posts. Finally, if the positive lead from the power supply goes to the left connecting post of one coil, the wire from the other post of the first coil should go to the left post of the second coil. See sketch below.) Connect the DC voltmeter in parallel with the power supply, as shown in the sketch below. D



11. Now with the power supply turned off, measure the location of the beam, both x- and y-coordinates. Now apply voltages from -5 V to maximum voltage of the power supply, in steps of 1 V, and read the (x- and y-) position of the beam each time. Record on Data Table B.
12. Disconnect one of the coils and connect a single coil to the power supply. Remove the CRT from its stand and place it so its axis goes through the coil. The two are now co-axial. Again record the position of the beam as you increase the voltage from 0 to maximum, in 1 V steps.

PROCEDURE C

13. If time allows, reconnect the Power Amplifier to the horizontal plates, as in Procedure A, and this time choose the saw tooth pattern on the Power Amplifier window. See sketch below, and match to one of the choices in the window.



14. Now increase the voltage to +10 V on the Power Amplifier, and turn it on. Draw the shape you see in Data Table C. This varying voltage should sweep the beam across the screen, and provide the beginning of an oscilloscope function. If the beam becomes blurry, try changing the frequency in steps, down to 1 Hz, to see if that helps. Record what you see as you change the frequency.

PROCEDURE D

15. This procedure is calculation, and may be performed after the lab period if time is short. On the Data Tables, calculate the displacements (Δx or Δy) by subtracting the $V = 0$ position value from all the other position values, for each Data Table.
16. Now plot six graphs, showing the x or y displacement vs applied voltage for each case. Clearly label all graphs. For the two magnetic cases plot separate graphs for the x - and y -directions, unless the deflection for one of these directions is too small to graph. This may be done by hand or on an Excel spreadsheet.

QUESTIONS

1. From the graph for Data Table A, is the predicted linear relation between V and displacement (that is, between applied voltage – and E intensity - and deflection of the electron beam) for Data Table A observed? Comment.
2. From the graph, what is the relation between applied voltage and deflection for Data Table B? Is the relation linear?
3. Compare the deflections in the two magnetic field parts, one with the magnetic field perpendicular to the CRT axis, and the other with the magnetic field parallel to the CRT axis. In which case was the deflection larger? Were there any other notable differences?
4. What would happen if, when you applied the sawtooth voltage to the horizontal deflection plates, you simultaneously applied a sinusoidal voltage ($V = V_m \sin\omega t$) to the vertical deflection plate? This is the start of a functioning oscilloscope.

DATA TABLE A

DATA TABLE B

x	Δx	V	y	Δy	V	x	Δx	y	Δy
					-5				
					-4				
					-3				
					-2				
					-1		0		0
		-5			0				
		-4			1				
		-3			2				
		-2			3				
		-1			4				
	0	0		0	5				
		1			6				
		2			DATA TABLE B 2				
		3			0		0		0
		4			1				
		5			2				
		6			3				
		7			4				
		8			5				
		9			6				
		10			7				

All voltages measured in Volts, all positions and displacements in cm.

COMMENTS FOR PROCEDURE C: