LAB 4
Deflection of Electrons in an Electric Field

OBJECTIVES
1. Learn the basics of electron deflection tubes.
2. Predict and measure the vertical deflection of an electron in an electric field.
3. Observe the arbitrariness of where the reference point of the electric potential is set.

EQUIPMENT
Deflection tube, tube stand, electrostatic power supply, kilovolt power supply, leads; Van de Graaff, Faraday Cage, electric pom-pom, plastic bucket

THEORY
The electron deflection tube enables the deflection of electrons in an electric field to be studied quantitatively. The electric deflection takes place in the field of two capacitor plates which are built in the tube. Electrons are evaporated off a hot cathode (negative). They are accelerated towards an anode (positive) using a high voltage. They emerge from a hole in the anode with a fairly uniform velocity. With no voltage between the deflecting plates, the electron beam follows a straight line. With a voltage connected to the plates, the electrons experience a vertical force. The constant vertical force causes the beam to follow a parabolic path. This will be increasingly curved as the deflecting voltage is increased.

PROCEDURE
Part 1: The Electron Gun
a. Set up the deflection tube in its special stand.
b. Studying the deflection tube and its diagram. Explain what role the terminal node voltages F1, F2, C, and A play. Now explain in detail how an electron beam is generated in the deflection tube.
c. Without turning on the kilovolt power supply, connect the 6.3 V supply to the heater filament (at terminals F1 and F2). Turn the HIGH VOLTAGE ADJUST to zero and connect a voltage across the cathode and anode potential (node voltages C and A).
d. Turn on the kilovolt power supply and note that the light from the heater filament is on. Starting with zero volts, increase the potential difference to about 3 kV: a fluorescent line appears that is the path of the electron beam (travels in a straight horizontal line).

Warning: after you have completed your observations and without turning off the power supply, turn the HIGH VOLTAGE ADJUST to zero. The light from the heater filament will stay on.

Part 2: Deflection of Electrons in an Electric field
a. Use Newton’s 2nd law and the projectile equations in two-dimensions to predict the vertical deflection y of an electric charge moving through an assumed uniform E-field as a function of horizontal distance x, charge e, electric field E, velocity v, and mass m.
b. Rewrite this equation using the following two steps.
   • Use conservation of energy to replace the velocity of the electron beam with the accelerating potential difference \( \Delta V_{\text{anode}} \).
   • Replace the E-field function between the parallel plates with the potential difference \( \Delta V_{\text{plates}} \) across the parallel plates.

The vertical deflection equation as a function of position x, plate separation d, potential differences \( \Delta V_{\text{anode}} \) and \( \Delta V_{\text{plates}} \) is
\[ y_{\text{thy}} = \frac{3 \Delta V_{\text{plates}}}{16 \Delta V_{\text{anode}} d} x^2 \]

**Important Note:** The electric field of two infinite plates is related to the voltage across and the distance between the plates: \( E = \frac{\Delta V_{\text{plates}}}{d} \). However, these plates are finite and the electric field is smaller. This can be taken into account in the experiment by a correction factor such that \( E_{\text{expt}} = 0.75 \frac{\Delta V_{\text{plates}}}{d} \).

**Conceptually Predicting and Verifying the beam deflection & trajectory**

c. Conceptually predict the “vertical drop” of the electron beam trajectory (relative to situations (i), (ii) and (iii)) when the voltage across the accelerating anode \( \Delta V_{\text{anode}} \) to the voltage across the deflection plates \( \Delta V_{\text{plates}} \) is adjusted to the following three situations: (i) \( \Delta V_{\text{plates}} = \Delta V_{\text{anode}}/2 \), (ii) \( \Delta V_{\text{plates}} = \Delta V_{\text{anode}} \), and (iii) \( \Delta V_{\text{plates}} = 2 \Delta V_{\text{anode}} \).

d. Connect the kilovolt power supply across the deflection plates and the accelerating anode for situation (i) \( \Delta V_{\text{plates}} = \Delta V_{\text{anode}}/2 \). Starting from 0 V, increase the voltage \( \Delta V_{\text{plates}} \) to 5 kV in 0.5 kV increments. You should now see a curved trajectory due to the vertical electric force applied to the electron beam. **CAUTION:** do not increase the voltage greater than 5 kV. Draw a sketch of the electron beam (or take a picture with your cellphone).

e. Now repeat step (2d) for the voltage settings described for situations (ii) and (iii). Did the predicted trajectories of the electron beam for cases (i), (ii), and (iii) compare as expected with the experimental results. Explain your reasoning using short concise sentences.

**Predicting and Measuring the beam deflection & trajectory for \( \Delta V_{\text{anode}} = \Delta V_{\text{plates}} \)**

f. Connect the full kilovolt power supply across both the deflection plates and the accelerating anode. Starting from 0 V, increase the voltage \( \Delta V_{\text{plates}} \) to 3 kV. You should now see a curved trajectory due to the vertical electric force applied to the electron beam.

g. Take a picture with your cellphone of the trajectory and with the help of the instructor, use Tracker to measure the horizontal and vertical components \((x_{\text{expt}}, y_{\text{expt}})\) of the trajectory. Transfer your data into Excel and recorded your data into a table.

h. To analyze your data
   - Compare theoretical \( (y_{\text{thy}}) \) and experimental vertical deflections \( (y_{\text{expt}}) \) for every value \( x_{\text{expt}} \) using a percentage to compare; how do they compare?
   - Plot \( y_{\text{thy}} \) and \( y_{\text{expt}} \) on a single graph.

**Part 3: Estimating the Voltage of a Van de Graaff (\( \equiv \text{VdG} \))**

a. With the grounded sphere in contact with the metal dome of the VdG, pull the grounded sphere away until sparks are jumping to it from the VdG dome. Try to make the spark length be as long as possible. Make several measurements of the longest possible spark length.
   - You may have to experiment with the motor control speed of the VdG to make this happen.
   - How will you do this, since you cannot simply hold up a meter stick while the VdG is sparking?

b. Choose the longest spark length as your measure (call this \( d_{\text{max}} \)) and using the dielectric breakdown of air, calculate the potential \( V_{\text{thy}} \) of the sphere.

c. Advertisements for this type of VdG typically state that it will produce voltages as high as 400,000 V. Is this a reasonable value, taking into account various leakages? What factors might cause the actual potential to be smaller than calculated?
Part 4: Faraday Cage with a Van de Graaff

a. Set the electric pom-pom close to the VdG, turn on the generator, and observe and record the results. When done, turn off the VdG and don’t forget to discharge the dome afterwards.

b. Now place the electric pom-pom inside the Faraday cage and repeat step (4a). Move the Faraday cage even closer to the dome using a meter stick. How are the strings of the electric pom-pom behaving? Explain your reasoning.

c. Repeat part (4b) using a partial Faraday cage.

d. Repeat part (4b) using a plastic bucket.