Name: Section: 202L- Date:

Experiment 3: The Determination of the Charge of an Electron (“Millikan's Experiment”)

Objectives

- To learn to take good measurements
- To learn how to estimate and propagate errors
- To verify the quantized nature of charge and determine that charge.

Equipment

- One “Complete Millikan Apparatus”
- One atomizer with latex spheres in suspension

Safety

Voltages in excess of 50 V are utilized within the apparatus. Do not disassemble the apparatus with it connected to power.

Introduction

In 1896, J.J. Thompson determined that the “rays” produced by a Cathode Ray Tube were actually charged particles. He made decent measurements of the mass and charge of these particles, but it was Robert Millikan and Harvey Fletcher who made the most accurate measurements of the particle's charge in their famous “Oil Drop” experiment in 1909. This experiment involved getting tiny oil droplets to acquire some charge and then injecting those droplets into a chamber containing an electric field. By watching the motion of the droplets in the electric field, the charge of each droplet can be determined.

The important part of the experiment was to watch *many* of these droplets. Each one will carry a different charge. By recording the measured charge on each droplet, it was found that the charge it acquired was always an integer multiple of some fundamental value. This value is the charge of a single electron.

You will be replicating their experiment using more modern equipment. However, **this experiment is still demanding and will require attention to detail**. Because it may take you some time to learn how to operate the equipment, the lab will be broken into two parts. On the first day, you should become familiar with the apparatus---how to use it and how to track the tiny particles within it. If you can, you should try and take some data. On the second day, you should devote yourselves to taking accurate data so that you can demonstrate the quantization of charge and determine the size of the quanta.

Theory

Instead of oil droplets, this experiment will use tiny polystyrene spheres. This way, there is no need to devote time to measuring the mass of each sphere---it can be calculated from the known radius and density. When the atomizer bulb is squeezed, these spheres are propelled from the reservoir through a tube. The friction between the tube and a sphere will cause some charge to transfer between the tube and the polystyrene sphere. This effect---where two objects which rub against each other develop a charge---is called **triboelectric charging**. The only way to know how much charge the sphere acquired is to watch it move under an electric force. This is why there is an electric field within the viewing chamber. Below, we will do a brief analysis of the forces on the spheres once they reach the viewing chamber.

Mechanics

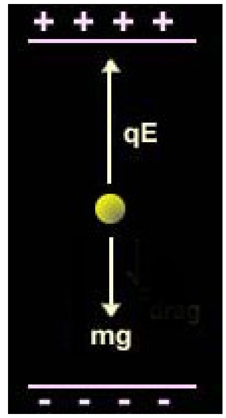

Figure 1: Millikan Free Body Diagram

When a charged particle enters a region containing air and an electric field, it is subject to three forces: gravity, air friction, and the electric force. However, when the particle is stationary, we can analyze the forces with the Free Body Diagram shown in Figure 1.

Gravity

The force of gravity on the particle is the familiar force $F_g = -mg$

However, the polystyrene spheres are so tiny that they are better described by the density of the polystyrene, ρ, and the radius of the sphere, *r*. In that case, the mass of the sphere is given by

$$m = \rho V = \rho\left(\frac{4}{3}\pi r^3\right)$$

So that the force of gravity becomes

$$F_g = -\rho\left(\frac{4}{3}\pi r^3\right) g \qquad (1)$$

Electrical Force

The electrical force is given by the formula you have worked with in class:

$$F_E = qE \qquad (2)$$

Electric Fields

The viewing chamber has an electrical plate for its ceiling and one for its floor, so it can be considered a parallel-plate capacitor. You will apply a voltage, *V*, to the capacitor plates, and the electric field between the plates is given by

$$E = \frac{V}{D} \qquad (3)$$

where *D* is the gap between the plates. This gap is approximately 5.0 millimeters which you should verify before beginning the experiment.

Computation of the Charge of the Sphere

When the particle is stationary, the forces will be balanced. Setting the electric force equal to the gravitational force,

$$qE = mg$$

$$q\frac{V}{D}=\rho\left(\frac{4}{3}\pi r^3\right)g$$

We can solve this equation for the charge, q, on the particle:

$$q=\frac{\left[\rho\left(\frac{4}{3}\pi r^3\right)g\right]D}{V} \tag{4}$$

During the experiment, you should know every value on the right side of Equation (4).

Experimental Procedure

To get good data for this experiment, you **must** pay attention to detail. It will take time to get used to spotting the particles and the difference in speeds between particles can be very small. There are two lab periods devoted to this experiment: use them judiciously.

Set Up

1. Level the unit (the bubble should be inside of the circle) by rotating the three feet underneath the unit.
2. Ensure that the Voltage Selector Switch is set to “0”
3. Rotate the Voltage knob fully CCW.
4. Bring up the program “Applied Vision 4.”
5. Turn on the unit by flipping the power switch on the front. You should see black lines on a blue background.
6. The reticle lines and number(s) should be in focus. If they are not, gently slide the camera off of the microscope, look into the microscope and rotate the Eyepiece Fine Tuning ring until the reticle lines are in focus. Then replace the PupilCam by gently sliding it ***all the way*** onto the microscope. You may need to shift the camera around a little so that the image is uniform.
7. The reticle lines should be horizontal. If they are not, gently rotate the PupilCam until they are. If the number(s) are upside down, that will be fixed in step 10.
8. Click the “Camera Resolution” button and select “1920x1080-MJPEG.”
9. Click the “Full Screen” button.
10. If the number(s) are upside-down, click the “up/down” arrow icon in the upper right of the screen.
11. Set the Voltage Selector Switch to “+”
12. Set the voltage to about 100 V by rotating the Voltage knob
13. Set the Voltage Selector Switch back to “0”

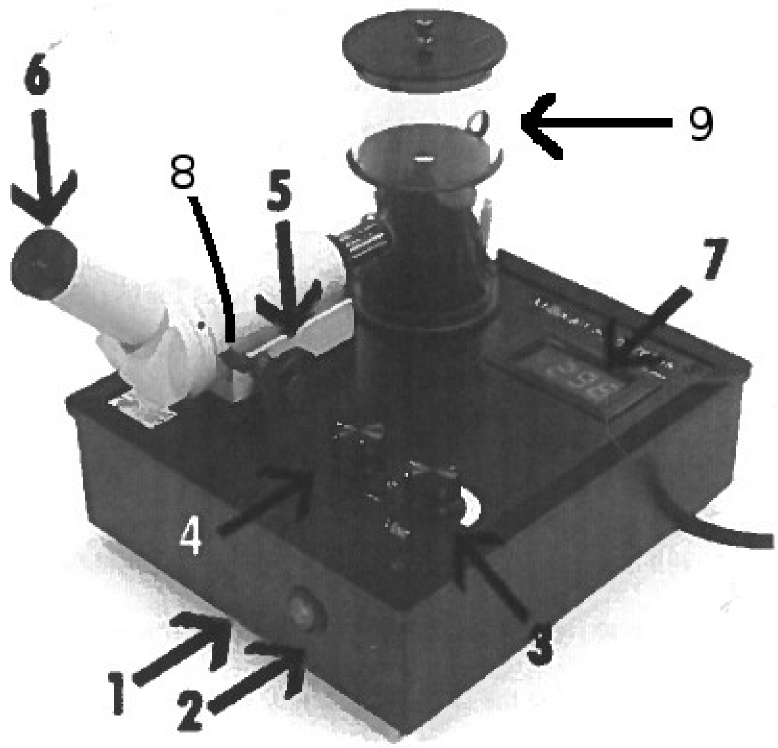

Figure 2: Device Layout: (1) Leveling Feet (underneath); (2) Power Switch; (3) Voltage Adjustment Knob; (4) Voltage Polarity Switch; (5) Focus knob; (6) Eyepiece Fine Tuning; (7) Voltage Readout; (8) Eyepiece Lock Screw; (9) Upper Chamber

Preparing to take Data

1. Fill the atomizer with the polystyrene sphere solution so that the bottom of the tube is in the solution.
2. Pump the atomizer until you can feel a mist coming out of the front end.

You are now ready to practice taking some data.

Operating procedure

Insert the atomizer nozzle into the upper chamber and squeeze the atomizer bulb **one time** while watching the monitor. Look for tiny pinpoints of light which are the spheres. Take some time moving the focus in and out a little to find the cloud of spheres you injected into the chamber. If each member of your lab team is unsuccessful in locating the spheres after five or ten minutes, ask your instructor to help.

Once you see the cloud of spheres, set the polarity switch to "+". You will see the spheres move either up or down depending on the charge of the sphere. The fast-moving spheres will grab your attention. You must ignore them and concentrate on the slow-moving particles. Slowly change the voltage until one of the spheres stays in place. Adjust the voltage so that it stays in place for thirty seconds to one minute. Once you have this voltage, record it in your data sheet.

To take the next data point, squeeze the atomizer bulb **one time** to inject another cloud of spheres into the chamber.
Always make sure that the polarity switch is set to "0" before squirting more particles into the chamber.

There are hundreds of particles injected into the chamber with each squeeze of the atomizer bulb. **Wait for a few minutes looking for particles to enter your field of view before injecting more particles into the chamber.** During this time you should be adjusting the focus of the eyepiece back and forth a little until you find a particle that you can track.

Each member of the team should take some time squirting the atomizer, finding particles, setting the polarity switch to "+", and adjusting the voltage to bring one sphere to a halt. Take your time and be as accurate as possible.

For good data analysis, each team member should measure 30—50 particles.

Clean Up

Before you leave, you must clean up your station and return it to the state you found it in:

1. Set the Voltage Polarity switch to "0," rotate the Voltage knob fully counter-clockwise, and switch off the unit.
2. Use the focus knob to back the microscope out of the clear, plastic chamber housing and gently remove the housing.
3. Gently rinse off the chamber housing and set it on a paper towel at your station to dry.
4. Clean up any spills at your station and leave the atomizer on top of the storage box.

Data Analysis

1. Your first step in analyzing your data is to enter the voltages required to stop each particle you observed into a spreadsheet. Enter them in order of **increasing** (absolute) value.
2. Compute the electric field produced and the charge of each particle you observed (in Coulombs) using equations (3) and (4).
3. If you then make bar or scatter graphs of Electric Field vs. Particle Number and Charge vs. Particle Number (with your new numbering scheme) you should find that the fields and charges of the particles break up into groups. The jumps may be easier to spot with the field plot. You may share your electric field and charge data with the class if your instructor wishes to combine data sets.
4. For each group, compute the average and standard deviation. This will be your measured charge, q_i, and uncertainty, δq_i, for each group.
5. Look carefully at your graph and you will be able to measure the smallest jump in measured charge. This is your step size, N.
6. Find the average q/N and uncertainty. This is your experimentally determined electron charge.

Raw Data

Quantity	Value	Uncertainty
Temperature in Lab, T		
Radii of polystyrene spheres, r		
Density of spheres, ρ		
Plate Spacing/Chamber height, D		

#	Voltage to stop (V)	Electric Field (V/m)	Computed Charge (C)	#	Voltage to stop (V)	Electric Field (V/m)	Computed Charge (C)
1				24			
2				25			
3				26			
4				27			
5				28			
6				29			
7				30			
8				31			
9				32			
10				33			
11				34			
12				35			
13				36			
14				37			
15				38			
16				39			
17				40			
18				41			
19				42			
20				43			
21				44			
22				45			
23				46			

Lab Report

Introduction

Write a few sentences about what you set out to measure and how you will compare the measured values with theory. Do *not* include details here. That is the job for the rest of your report. (Hint: write this section *last.* This way you'll have the whole experiment in your head when you write it and can properly foreshadow the results.)

Theory

Your theory section should describe the mathematical model that you expect the experiment to match. It should also detail the mathematical method by which you will compute your main values and your uncertainties. Make a prediction of your results in this section. Read your Lab Manual for instructions on how to format equations for this section.

Methods

In a few paragraphs, describe the methods you used to take your data, any problems you encountered and how you solved them. **You will be graded on your ability to clearly describe what <u>you</u> did.** The description should be clear enough that someone else could reproduce your results by reading this section. **Never use the second person "you" in your lab report.** ***Be Careful:*** There is a fine line between giving enough information so that a competent student could reproduce your results and writing *way too much detail.* The idea is to be <u>concise.</u> If this section is longer than two pages, it is too long.

Data

Include the following items in this section:

- Your histogram (or scatter plot) of Voltage vs. Particle Number.
- Your histogram (or scatter plot) of Electric Field vs. Particle Number.
- Your histogram (or scatter plot) of Charge vs. Particle Number.
- Your average value of the electric charge of the electron and its uncertainty.

Results and Conclusion

Compare your expected results from your Theory section to the results you obtained in your Data section. **This is a technical document**. Do not use weasel words such as "about," "almost," "close to," "kind of," "roughly," or "sort of." Use proper numerical comparisons such as percent differences or percent errors. **You must quote uncertainties for every value you present!** Discuss your uncertainties and how you might be able to reduce them. Include the answers to the following questions:

- Discuss your scatter plots. How did you determine your cut-off values for your charge groupings? Was there a large standard deviation within each group?
- How does your value for the charge on an electron compare to the accepted value?

Appendix

- Include your signed and completed Raw Data page.
- Include one sample calculation for each equation you used.