Practical Physics

Millikan Lab

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Introduction:

If the charged oil drop is floating, then the forces acting on it are gravitational force, air buoyancy, and electric force. And the net force is zero:

$$g\left(m_{oil} - m_{air}\right) - \frac{QV_{stop}}{d} = 0 \tag{1}$$

Where g is gravitational acceleration, m_{oil} is mass of oil, m_{air} is mass of displaced air by oil, Q is net charge of oil drop, V_{stop} is the stop voltage, and d is the plate separation.

If the oil drop is dropping with terminal velocity, then the forces acting on it will be gravitational force, air buoyancy, and air drag. And the net force acting on it is zero:

$$g\left(m_{oil} - m_{air}\right) - 6\pi r \eta v_t = 0 \tag{2}$$

Where r is the radius of oil drop, η is the dynamic viscosity of air, it is taken to be $1.827 \cdot 10^{-5} Pa \cdot s$, and v_t is the terminal velocity.

If the oil drop is moving upward, then the gravitational force, air buoyancy, air drag, and electric force will be acting on the oil drop:

$$ma = -g\left(m_{oil} - m_{air}\right) + QE - 6\pi r \eta v_2 \tag{3}$$

Where a is the acceleration.

Exercise 1:

Equation 2 can also be written as:

$$\frac{4}{3}\pi r^3 g\left(\rho_{oil} - \rho_{air}\right) = 6\pi r \eta v_t \tag{4a}$$

$$r = \sqrt{\frac{9\eta v_t}{2g\left(\rho_{oil} - \rho_{air}\right)}} \tag{4b}$$

Where ρ_{oil} and ρ_{air} are density of oil and air, they are taken to be 875.3 kg/m^3 and 1.204 kg/m^3 respectively, combing equation 1 and 2:

$$\frac{QV_{stop}}{d} - 6\pi r \eta v_t = 0 \tag{5a}$$

$$Q = \frac{6\pi r \eta v_t d}{V_{stop}} \tag{5b}$$

Substituting equation 4b into 5b:

$$Q = \frac{6\pi \eta v_t d}{V_{stop}} \sqrt{\frac{9\eta v_t}{2g\left(\rho_{oil} - \rho_{air}\right)}} = 6\pi \eta d \sqrt{\frac{9\eta}{2g\left(\rho_{oil} - \rho_{air}\right)}} \frac{v_t^{3/2}}{V_{stop}} \tag{6}$$

Exercise 2:

The acceleration is controlled to be 0 when the oil is going upward, therefore equation 3 can be written as:

$$0 = -g\left(m_{oil} - m_{air}\right) + QE - 6\pi r \eta v_2 \tag{7}$$

Substituting equation 2 into equation 7:

$$0 = -6\pi r \eta v_t + \frac{QV_{up}}{d} - 6\pi r \eta v_2 \tag{8a}$$

$$Q = \frac{6\pi r \eta\left(v_2 + v_t\right) d}{V_{up}} \tag{8b}$$

Substituting equation 4b in 8b:

$$Q = 6\pi \eta d \sqrt{\frac{9\eta}{2g\left(\rho_{oil} - \rho_{air}\right)}} \left(v_2 + v_t\right) \frac{v_t^{1/2}}{V_{up}} \tag{9}$$

Materials:

Chamber (plate capacitor), oil atomizer with rubber bulb, socket pair for charging the plate capacitor (*connected to DC power supply with adjusting knob*), light source, microscope connected to the CCD camera.

Procedure:

First, 57 excel files were created and numbered from 1-57 in preparation to save the live data from the millikan oil drop program onto the excel sheets. The millikan video tracker was launched and the DC power supply unit was powered on. The millikan oil droplet atomizer was lined up with the entrance ports of the plate capacitor chamber so that the maximum amount of oil droplets could enter the chamber once the rubber bulb was pumped. The lower value adjustment was set at around 20-30, and the upper value and gain values were set and kept set at their maximum settings. The rubber bulb was pumped 2-3 times, shooting oil droplets into the chamber, which were then identified by the camera and seen on screen. Many oil droplets were observed, most of them falling downward, with some upward-moving droplets located, as those are the ones that will be traced. Then, the millikan video tracking software was used to surround, track, and record the oil drop's movement to the assigned excel file.

Once a droplet was chosen for testing, the lower value, initially at a position around a value of 20, was increased so that the oil droplet was isolated as a white dot on a black screen. The surrounded droplet's location on screen was traced and recorded, and then the process with another oil drop on another excel sheet was repeated. the data that was recorded were the y-axis locations on-screen of the location of the oil droplet over time. These coordinates were then translated into a position-time relation that could be used to determine the velocity and charge of each oil droplet. This process was repeated 60 times in total.

Data and Discussion:

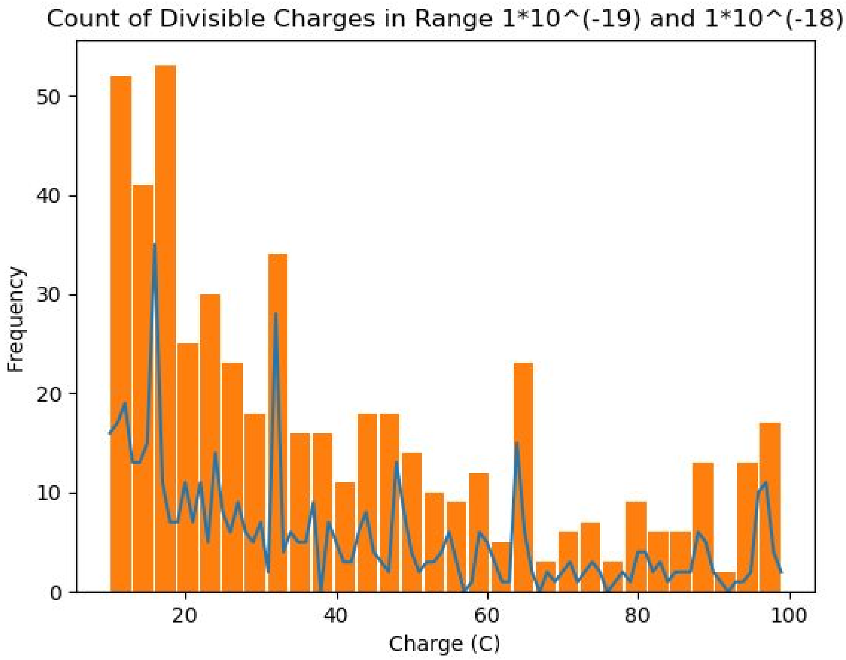

*Figure 1: 'Count of Divisible Charges in Range 1*10^(-19) and 1*10^(-20)',*

The elementary charge will be the greatest common divisor of all experimental charges, and it is also representative that all charges are divisible by an integer multiple of the elementary charge. By dividing the experimental charges by multiple of a smallest division $1 \cdot 10^{-20}$ C, ranging from $1 \cdot 10^{-19}$ C to $1 \cdot 10^{-18}$ C, it will be possible to observe that most of the charges are divisible around charges of multiple of the elementary charge.

The peaks of trendlines are; $1.7 \cdot 10^{-19}$ C, $3.2 \cdot 10^{-19}$ C, $4.7 \cdot 10^{-19}$ C, $6.5 \cdot 10^{-19}$ C, $8.6 \cdot 10^{-19}$ C, $9.6 \cdot 10^{-19}$ C. The greatest common divisor of these charges is the average interval between peaks, where the uncertainty is the standard deviation of the charges, therefore the experimental elementary is $1.6 \cdot 10^{-19} \pm 0.3 \cdot 10^{-19}$ C.

Question 1:

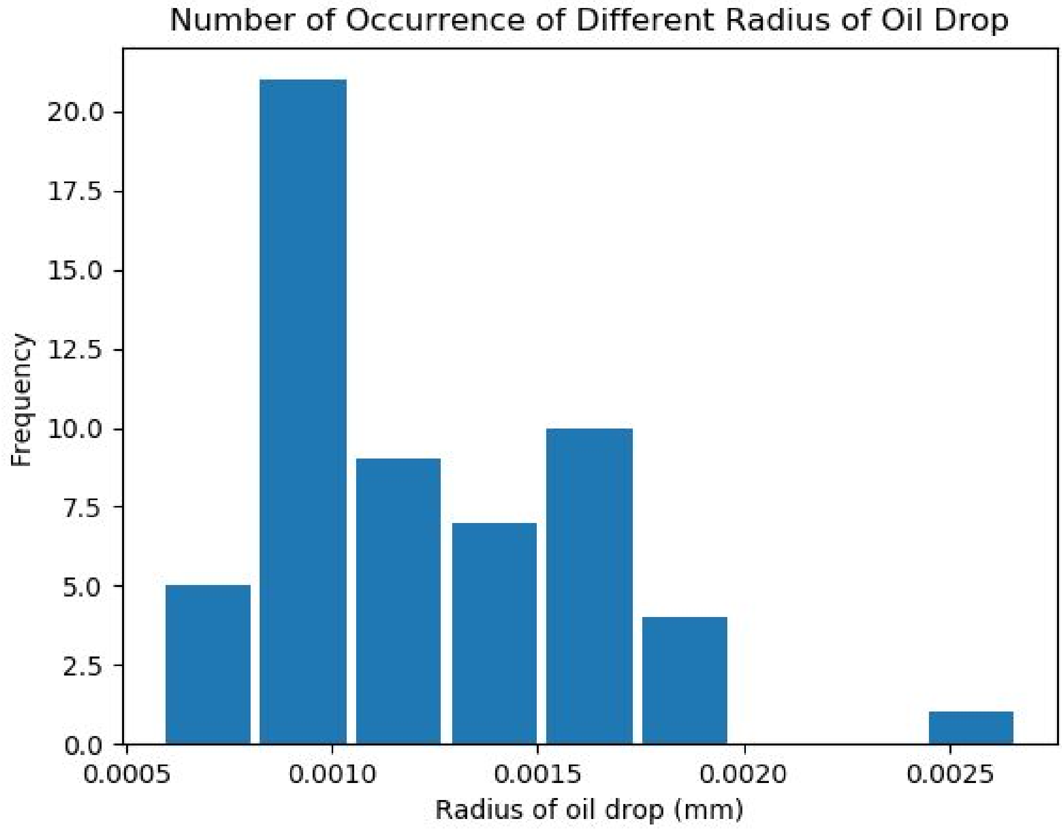

Figure 2: 'Number of occurrences of different radius of oil drop'

The radius of the oil drops can be determined by its terminal velocity using *equation (4b)*. The typical oil drop in this experiment had a radius between 0.003 mm and 0.018 mm. A radius between 0.008 mm and 0.01 mm are most common, acting as the mode of the radius data. The average radius was 0.001229 mm.

Question 2:

If the air buoyant force is set to zero:

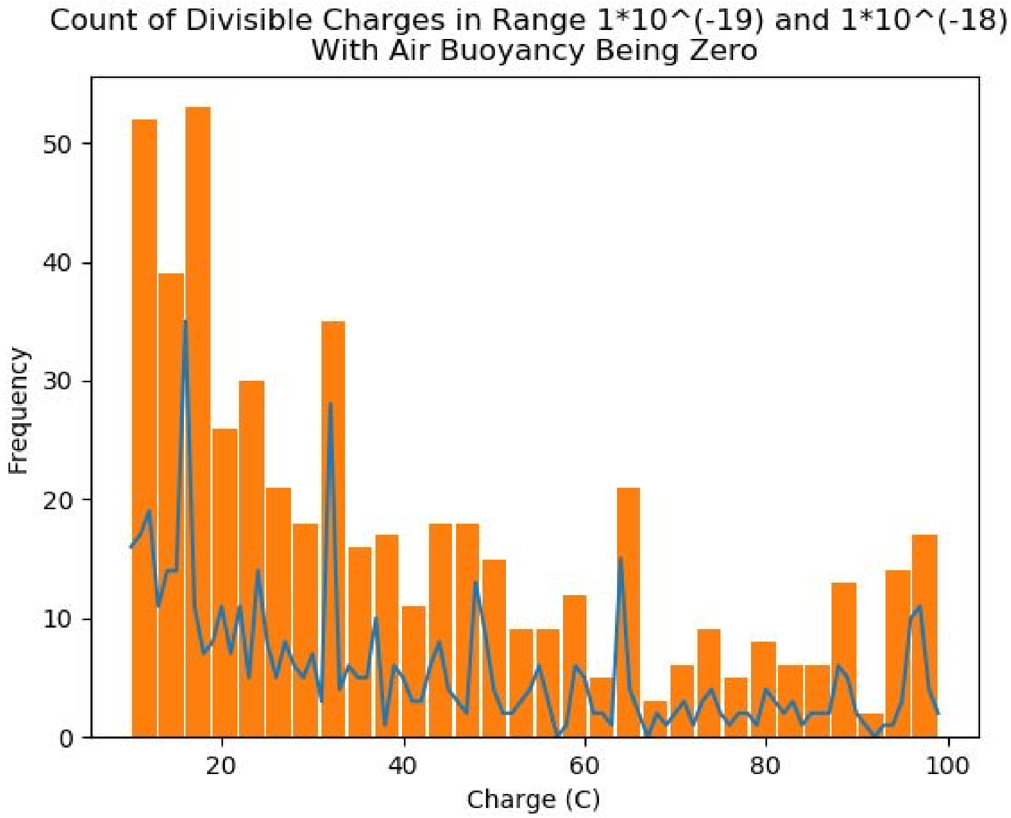

*Figure 3: 'Count of Divisible Charges in Range 1*10^(-19) and 1*10^(-20) with air buoyancy being zero'*

The peaks are the same as they were with the factor air buoyancy taken into account, therefore it does not make a difference experimentally. This makes sense, as air buoyancy is negligible in comparison with the force of gravity.

Question 3:

Figure 2 shows that the radius of oil drops in this experiment were similar, therefore, the effect of radius on accuracy of result could not be determined in this experiment. However, since air drag has an approximate linear proportionality to the radius of the oil drop, having a smaller radius should yield a better result, as with a larger radius, the accuracy of the linearity of the fit decreases, making more room for error and uncertainties surrounding the charge and velocity of the larger oil droplet.

Conclusion:

The millikan oil drop experiment was key in identifying the significance of charged particles within a capacitor created by two oppositely charged plates, provided that charges can move in any direction with any charge and amount of charge, where the size of the charged molecule, the sign and size of the charge, and the power of the charged plates all are factors in the reaction of the particles within the capacitor. With the collected data, the relationship between these factors was confirmed, and the significance of the forces of air and gravity were determined, where gravity heavily outweighed air buoyancy. The proportionality between the size of the charged oil drop and its velocity in a direction is seen in figures (1) and (3), as when the significant data points can be seen as a sinusoidal wave relationship, where there are peaks that are representative of the data points that exist as determinant for the solution to the elementary charge for the collected data set, $1.6\cdot10^{-19}\pm0.3\cdot10^{-19}$ C, which is extremely close to the reference elementary charge, $1.60217662 \times 10^{-19}$ C, even with the slight variation in the experimental elementary charge due to possibilities of human and experimental equipment error and standard deviation of those uncertainties.