

# PHY 252 Lab 4: Millikan oil drop/charge of electron

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The purpose of this experiment is to measure the smallest unit into which electric charge can be divided, that is, the charge  $e$  of an electron. The method is essentially the one employed by R.A. Millikan in 1910. The essence of the experiment is to measure the terminal velocity of a falling droplet to measure its radius  $r$  and thus mass  $m$ , and then to suspend the droplet with an electric field so that one can measure its charge  $q$  from  $qE = mg$ . By repeating many measurements, Millikan was able to show that charge comes in integer multiples of a fundamental value. Millikan used oil droplets for his experiments; you'll use micrometer-scale polystyrene spheres instead.

When objects move through a fluid, one can have either turbulent or laminar flow. The dividing line between the two is given by the Reynolds number  $R = \rho v L / \eta$ , which is the ratio of inertial to viscous forces found from the fluid density  $\rho$ , dynamic viscosity  $\eta$  (some books use  $\mu$  to represent this), velocity  $v$ , and characteristic length  $L$  of the object moving through the fluid. Low Reynolds number ( $R \lesssim 30$ ) corresponds to laminar flow, while high Reynolds number ( $R \gtrsim 3000$ ) corresponds to turbulent flow. In the low Reynolds number limit (appropriate for micrometer-scale objects moving through air), the drag forces on a sphere with radius  $r$  is given by

$$F_d = 6\pi\eta r v. \quad (1)$$

In the high Reynolds number limit (appropriate for people and cars moving through air), drag forces are given by

$$F_d = \frac{1}{2}\rho v^2 A C_d \quad (2)$$

where  $A$  is the area of the object and  $C_d$  is a coefficient of drag which is typically in the range 0.2–1. The appearance of  $(1/2)\rho v^2$  tells you that the kinetic energy of the air pushed aside in turbulent flow is what determines the drag force. In the low Reynolds number limit (and neglecting the buoyant force of air, since its density is a thousand times lower than that of polystyrene), terminal velocity  $v_T$  is reached when  $F_d = mg$  so that there is no net acceleration; from this fact, Eq. 1, and  $m = (4/3)\pi r^3 \rho$ , one can find the radius  $r$  of the sphere to be

$$r^2 = \frac{9\eta v_T}{2\rho g} \quad (3)$$

and its mass to be

$$m = \frac{4}{3}\pi \left(\frac{9}{2}\right)^{3/2} \left(\frac{\eta v_T}{g}\right)^{3/2} \frac{1}{\sqrt{\rho}}. \quad (4)$$

Air at 25°C has a dynamic viscosity of  $1.85 \times 10^{-5} \text{ N}\cdot\text{s}/\text{m}^2$ , and polystyrene has a density of 1050  $\text{kg}/\text{m}^3$ , so for the polystyrene spheres used in this experiment you can readily determine their mass from their terminal velocity. Then, if you create an electric field  $E = V/d$  from a voltage  $V$  applied to plates a distance  $d$  apart, and thereby suspend a sphere by counteracting gravity, you can measure its charge from  $qE = mg$  or

$$q = \frac{mg}{E} = \frac{mgd}{V}. \quad (5)$$

## 1 Apparatus

A schematic of the apparatus is shown in Fig. 1, and a photograph is shown in Fig. 2. In the closed chamber, a uniform electric field  $E = V/d$  can be applied between two capacitor plates  $d = 0.40 \text{ cm}$  apart by adjusting a voltage  $V$  using the right-hand knob on the power supply shown in Fig. 3. The chamber is illuminated by a small lamp. Charged spheres (a suspension of latex in water and alcohol) can be blown into the chamber through a tubing and a nozzle, and be viewed there through a telescope with a calibrated scale (the spacing of graduations is 0.5 mm). Note that the telescope gives an inverted image.

1. Turn on the light and focus the telescope on the end of the nozzle which is used to blow spheres into the chamber. Then pull the nozzle back out of the field of view. Spheres can now be blown into the chamber by squeezing the rubber bulb.
2. Blow some spheres into the chamber and watch them (they will look tiny). They will quickly reach terminal velocity  $v_T$  and should all be falling at the same rate in the absence of an electric field. Measure this velocity by timing the travel of particles over a known distance with a stop watch. Repeat several times until you get a set of consistent values. Calculate the mass from the average terminal velocity.
3. Blow more spheres into the chamber and watch them falling. Now turn up the electric field. You will see them reverse direction and reach a new terminal velocity, which now depends on their charge  $q$ . Since you want to measure small charges, select one that is least affected by the  $E$  field and adjust the voltage  $V$  to hold it stationary. Write down the value of  $V$  (which determines  $E$ ), and repeat the measurement 20 or more times, trying to find spheres with slightly different charges.
4. Calculate  $q$  for each sphere, using Eqs. 4 and 5.

Now that you have a set of  $q_i$  measurements with  $i = 1, 2, \dots, N$ , you should make a histogram of your measurements. On the horizontal axis, pick intervals of charge  $q$  (for example,  $q = 0$  to  $0.2 \times 10^{-19}\text{C}$ ,  $0.2$  to  $0.4 \times 10^{-19}\text{C}$ , and so on), and then within each bin plot on the vertical axis the number of measurements that fall within that  $q$  range. Ideally you'll get one or more peaks around particular values of  $q$ ! Assign successive integers  $k = 1, 2, \dots$  to these peaks. Now plot  $q$  versus  $k$  for all of your data. Since we expect the relationship  $q = ke$ , the slope of a least squares fit should give you the electron charge  $e$ !

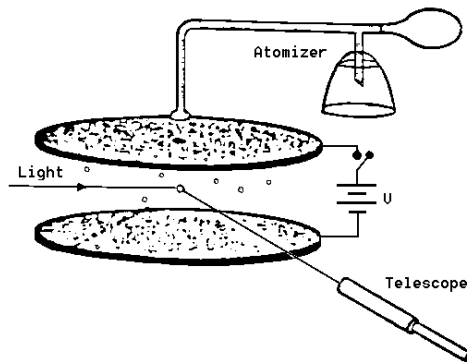


Figure 1: Schematic diagram of the Millikan apparatus. The atomizer squirts out small particles into a space between two plates with a voltage difference, and particles are viewed by examining their scattered light in a telescope.

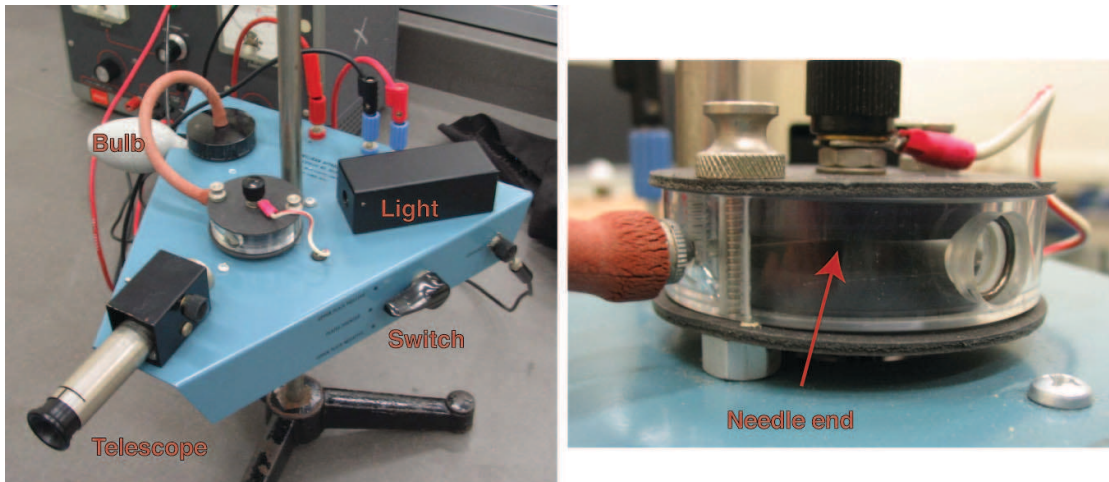


Figure 2: Millikan apparatus. You work the atomizer by squeezing the bulb at left; the telescope looks into the chamber which is shown at higher magnification in the image at right.

Figure 3: Voltage control for the Millikan apparatus. The knob at right allows you to adjust the voltage  $V$ , and the voltmeter above the power supply lets you obtain an accurate reading of  $V$ .

