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MILLIKAN OIL DROP EXPERIMENT

GOAL

- You will collect data that supports the idea that the electric charge is quantized and you will repeat the measurement which led to the first determination of this elementary charge.

OVERVIEW

The Millikan experiment

The electric charge of the electron was first determined (Robert Millikan, 1909) by measuring the velocities of tiny oil droplets subject to gravitational and electrical forces. You will repeat his experiment using very similar equipment, which consists essentially of an atomizer, charged parallel plates, a radioactive source and a telescope. See figure 1.

The basic idea of the experiment is simple and requires that the experimenter measure several transit times of small electrically charged masses under the simultaneous influence of several forces. An atomizer is used to introduce tiny droplets of a fluid (with mass density ρ_F) into a region of space bounded by two parallel plates of separation s. The squirting action of the atomizer tends to charge the tiny droplets which we will assume are spherical in shape with some diameter r. The plates can be made electrically charged and the motion of the droplets can be observed with the telescope. The radioactive source is used to ultimately vary the electric charge residing on the droplets.

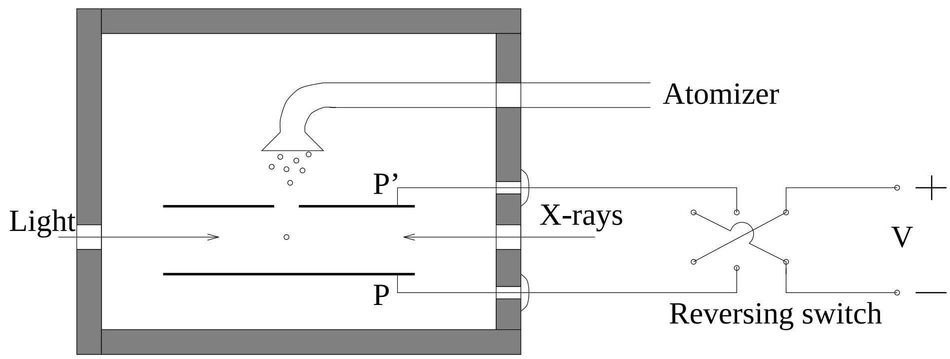

Figure 1: Millikan oil drop experimental setup.

If the parallel plates are *not* charged then the only forces acting on the droplet are gravitational (tending to pull the droplet downward), the bouyant force produced by the air, and a frictional force described by Stokes' law due to the interaction between the droplet and the air. In equilibrium, which occurs very rapidly for these droplets, each droplet moves with a constant velocity $\vec{v}$ and we have:

$$mg = kv + f_{\rm B}, \tag{1}$$

where $m = \frac{4}{3}\pi\rho_f r^3$, $f_{\rm B} = \frac{4}{3}\pi\rho_a r^3$, and $k = 6\pi\eta r$. The acceleration due to gravity at the Erath's surface is denoted by g, and the mass density and viscosity of air are given by ρ_a and η, respectively. With the exception of the radius of the droplet, all the physical parameters can be taken from standard references. (More about this below.) The quantity that takes a little bit more work to determine is the radius r of the droplet sphere. Actually, what is more useful to us is to calculate a quantity related to the radius of the droplet. This is done by first rearranging the above formula to solve for v, and then solving for the time it takes a spherical drop to fall through a known distance under equilibrium conditions. If the droplet's constant speed is v and it "falls" through a distance d, then the transit time $t_0 = d/v$ can be derived from Eq. 1 by first solving for v and then for t_0^{-1}:

$$1/t_0 = \frac{2}{9} r^2 (\rho_f - \rho_a) g/\eta d. \tag{2}$$

The quantity t_0 is a directly measurable one and is clearly related to the radius r of a droplet. Hence, by measuring the *time* it takes a droplet to travel a known distance, we can measure its size. So what? How do we acquire sensitivity to the electronic charge e. This is also done by measuring times.

Suppose now that the parallel plates of separation s have a potential difference V applied to them so that an electric field $\vec{E}$ exists in the region where the charged droplet moves. There is now an additional force acting on the droplet and equation ?? is modified to be

$$mg \pm qE = kv + f_{\mathrm{B}}. \tag{3}$$

Here q is the electric charge. The $+$ sign is appropriate if the electric force points in the same direction as the gravitational and the $-$ sign is appropriate when the two forces are opposing. If we now assume that the droplets are negatively charged (an assumption which can be checked during the experiment) and are some multiple n of a fundamental charge e so that $q = ne$, we can then again first rearrange this equation for v and then solve for the transit times for the case with an electric field present:

$$1/t_{\pm} = \pm\frac{Vne}{6\pi r\eta s} + 1/t_0. \tag{4}$$

The $+$ sign applies if $\vec{E}$ points up, the $-$ sign applies otherwise and V is voltage across the plates. You can also think of t_+ as the time it takes for a given droplet *to fall* a given distance when $\vec{E}$ is pointing up and t_- as the time it takes for the droplet *to rise* the same distance when $\vec{E}$ is pointing down. Clearly, these times, the quantities we will actually measure, can be related to e, our real physics interest.

We can express our results in terms of the transit times we will end up measuring:

$$1/t_{\pm} = \pm An + B \tag{5}$$

and

$$1/t_0 = B, \tag{6}$$

where $A = Ve/(6\pi\eta s)$ and $B = (2/9)r^2(\rho_f - \rho_a)g/(\eta d)$. Here, the $+$ and $-$ signs are applied as above and n is a n integer indicating the number of fundamental charges on the drop. The form of these two equations will aid the data analysis and are similar to the presentation that Millikan used. **Notice that To determine e, we will need to determine the constant A for a given droplet.**

The radioactive source is an emiiter of X-rays and when exposed to the droplets permits a droplet to have a few electrons ionized from it. This allows a given droplet to carry a varying amount of net charge.

Literature

1. R.A. Millikan, Phys. Rev. **32** (1911) 349.
2. A.C. Melissinos, "Experiments in Modern Physics", Academic Press, New York, 1966, pp. 2-8.
3. "Introduction to Modern Physics", E.E. Anderson, Holt Rinehart and Winston, 1982, pp. 20-24.
4. Stephen T. Thornton and Andrew Rex, "Modern Physics for Scientists and Engineers," Saunders College Pub., 1993.

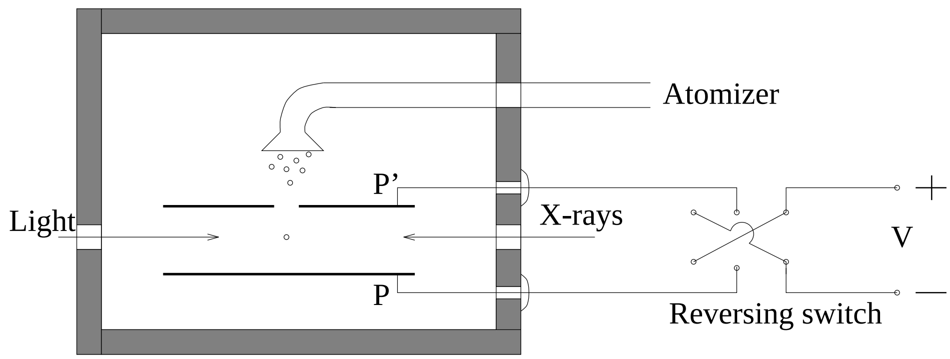

Figure 2: Exploded view of condenser assembly.

INSTRUCTIONS

1. Plate separation and other constant parameters

To estimate the electric field strength between the plates, we need to know the voltage difference between the plates and their separation s. Notice that the plates are separated by a plastic spacer (part G in Figure 2). Measure and record the thickness of this spacer with a micrometer. See me if you do not know how to use a micrometer.

The distance d over which you will measure transit times is defined by reticule lines marked on the viewing telescope. The manufacturer has kindly marked this value on the chassis.

Measure the temperature, T, and calculate the air viscosity coefficient, η. See Melissinos, for example, for a graph of η v. T. Other references are also satisfactory. You should measure the air temperature before and after the measurements.

2. Assembly of the condenser

Assemble the condenser according to figure 2. The droplet hole cover E can be omitted for easier injection of droplets into the space in between the plates.

3. Leveling

Level the apparatus using the three screws on the bottom of the main chassis. The apparatus must be well leveled so a drop can be kept in the viewing area for multiple measurements. If you observe that droplets drift to one side of the viewing area in the course of multiple measurements, then improve the leveling of the apparatus.

4. Potential between the plates

Turn the power on using the toggle switch on the top of the device. Hook up a voltmeter to the connections on the main chassis and measure the D.C. potential between the plates. In the first 5 minutes of operation, the potential may drift and should remain constant within 1% or so later on. You should check the potential from time-to-time. You can control this potential, in a limited range, by adjusting the potentiometer knob on the top of the chassis. Set the potential to the lowest value available.

5. Focusing

Insert a thin wire or pin through the hole in the center of the top plate. Move the focusing lever on the right side of the chassis, forward or backward, until the wire is in sharp focus. Adjust the orientation of the window on the housing to obtain the maximum illumination of the wire. Afterwards, do not disturb the position of the focussing lever.

6. Introducing drops into the condenser

For best visibility of the droplets the room should be dark, although you will need some light to read out the meters. Also, the reticule illumination control should be set so that the reticule lines are just bright enough to be easily visible.

Put the radiation source lever to the "on" position.

Place the nozzle of the atomizer into the hole of the condenser housing oven. Squeeze the atomizer bulb. Wait until you see drops in the viewing area. You should select a droplet which both: falls slowly and raises slowly, when the plates are charged with appropriate polarity. You can control the droplet in the viewing area with the plate potential switch which has three position: $+$, off, $-$.

Well visible drops are usually large and they fall quickly. They are also likely to acquire multiple charges. Look for faint, small droplets. Immediately after a drop is selected, move the radiation source lever to the "out" position.

VI. Time measurements

Measure the time of free fall and rise under the influence of the electric field as many times as you can for the same droplet (10 or more measurements are desirable).

If you still control the droplet after 10 measurements switch the radiation on for a few seconds in attempt to increase charge of the droplet. If you don't notice change in the raise time irradiate the droplet again.

Immediately after you have completed all time measurements for one droplet calculate its charge in units of the elementary charge. Your goal is to find a droplet with the lowest charge possible and find evidence for charge quantization. Measure charge for many different droplets.

VII. Analysis

You may find the data analysis technique adopted by Mellisios convenient. (See the literature references.) You are also free to use other techniques. Average different measurements of fall and rise times for each droplet and calculate the charge. What is the lowest charge you have been able to observe? Do you find any evidence for charge quantization? If you were to determine elementary charge from your data alone, what value would it be? How does it compare with the table value?

Estimate the accuracy of your time measurements from the spread of the individual time measurements around the average. Propagate the time errors into an error on the charge. What are the other possible errors in your charge determination?