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OPERATING INSTRUCTIONS

OIL DROP APPARATUS

CENCO NO. 71263

1. INTRODUCTION

In 1909, Robert Andrews Millikan, using an oil drop apparatus, succeeded in determining the actual value of *e*, the magnitude of the charge on an electron. Within a few months, he was able to prove the existance of the electron as a physical entity and by the end of the series of experiments, Millikan had established the approximate mass and size of the electron, confirmed Einstein's photoelectric effect equations, and experimentally derived Planck's constant.

The Cenco No. 71263 Oil Drop Apparatus is used to duplicate Millikan's classic experiments.

2. DESCRIPTION

The Oil Drop Apparatus, shown in Fig. 1, consists basically of two plates separated by a three millimeter illuminated gap. A 15 power, long-focus microscope with a graduated reticule for observing the drops is mounted on the apparatus. In operation, a cloud of oil is sprayed into the chamber above the top plate, and charged droplets fall through a small hole in this plate and into the gap between the plates.

Fig. 1

The Oil Drop Apparatus is equipped with two individually operated alpha ray sources; one in the chamber above the top plate, and one in the gap between the plates. The upper source is used to insure that the droplets are ionized before they enter the gap, and the bottom is used to change the number of electrons on the droplet inside the gap.

The built-in AC power supply can be used to demonstrate that the oscillation of a charged droplet in a changing field is directly proportional to the magnitude of the charge on the droplet. This behavior may be used as a basis for comparing the relative magnitude of the charges on several droplets.

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3. SPECIFICATIONS

Plate Gap, mm	3
Microscope Magnification	15
Operating Voltage, volts	115
Current Frequency, Hertz	50/60
DC Plate Potential, volts	0 to 500
AC Plate Potential, volts	2000
Power Consumption, watts	7
Overall Dimensions, inches	28 x 8 x 3

Theory: The electronic charge, or electrical charge carried by an electron, is a fundamental constant in physics. During the years 1909-1913, R. A. Millikan used the oil-drop experiment to make the first accurate measurement of the value of this constant and to demonstrate the discreteness, or singleness of value, of the electronic charge. The Millikan oil-drop procedure is still the most common method for this determination.

In the experiment, a small, charged drop of oil is observed in a closed chamber between two horizontal parallel plates. By measuring the velocity of fall of the drop under gravity and its velocity of rise when the plates are at a high electrical potential difference, data is obtained from which the charge on the drop may be computed.

In the experiment the oil drops are subject to three different forces: viscous, gravitational, and electrical. By analyzing these various forces, an expression can be derived which will enable measurement of the charge on the oil drop and determination of the unit charge on the electron.

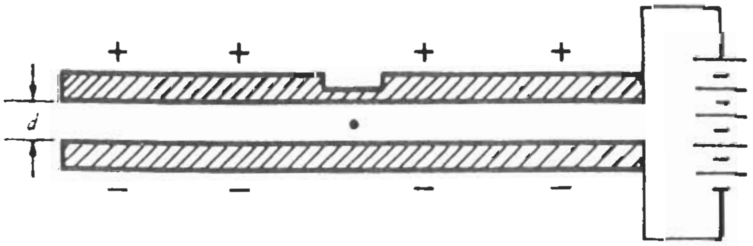

Fig. 1

When there is no electric field present, the drop under observation will fall slowly, subject to the downward pull of gravity and the upward force due to the viscous resistance of the air to the motion of the oil drop. The resistance of a viscous fluid to the steady motion of a sphere is obtainable from Stokes' law from which the retarding force acting on the sphere is given by

$$F_r = 6\pi a\eta v \qquad (1)$$

where a is the radius of the sphere, η the coefficient of viscosity of the fluid, and v the velocity of the sphere.

For an oil drop with mass, m, which has reached constant or terminal velocity, v_g, the upward retarding force equals the downward gravitational force and

$$F_r = mg = 6\pi a \eta v_g \qquad (2)$$

Now let an electrical field, E, be applied between the plates in such a direction as to make the drop move upward with a constant velocity, v_E. The viscous force again opposes its motion but acts downward in this case. If the oil drop has an electrical charge, q, when it reaches constant velocity, the forces acting on the drop are again in equilibrium and

$$Eq - mg = 6\pi a \eta v_E \qquad (3)$$

Solving equation (3) for mg and equating this to equation (2) we obtain

$$q = \frac{6\pi a \eta}{E} (v_E + v_g) \qquad (4)$$

The electric field, E, is obtained by applying a voltage, V, to the parallel plates of the condenser which are separated by a distance, d. Therefore,

$$q = \frac{6\pi a \eta d}{V} (v_E + v_g) \qquad (5)$$

From equation (5) it is seen that for the same drop and with a constant applied voltage a change in q results only in a change in v_E and

$$\Delta q = C \Delta v_E \qquad (6)$$

When many values of Δv_E are obtained, it is found that they are always integral multiples of a certain small value. Since this is true for Δv_E, the same must be true for Δq; that is, the charge gained or lost is the exact multiple of a unit charge. Thus the discreteness of the electric charge may be demonstrated without actually obtaining a numerical value of the charge.

In equation (5) all quantities are known or measurable except a, the radius of the drop. To obtain the value of a, Stokes' law is used. It states that when a small sphere falls freely through a viscous medium it acquires a constant velocity,

$$v_g = \frac{2ga^2(\alpha - \alpha_1)}{9\eta} \qquad (7)$$

where α is the density of the oil, α_1 the density of the air, and η, as stated previously, is the viscosity of the air. Since the density of the air is very much smaller than the density of the oil, α_1 is negligible and equation (7) solved to give

$$a = \sqrt{\frac{9\eta v_g}{2g\alpha}} \qquad (8)$$

Substituting this value of a in equation (5) gives an expression for q in which all the quantities are known or measurable:

$$q = \frac{6\pi d}{V} \sqrt{\frac{9\eta^3}{2\alpha g}} (v_E + v_g) \sqrt{v_g} \qquad (9)$$

Millikan in his experiments found that the electronic charge resulting from the measurements seemed to depend somewhat on the size of the particular oil drop used and on the air pressure. He suspected that the difficulty was inherent in Stokes' law which he found not to hold for very small drops. It is necessary to make a correction*, multiplying the velocities by the factor $(1 + \frac{b}{pa})$ where p is the barometric pressure (in centimeters of Hg), b is a constant of numerical value 6.17×10^{-6}, and a is the radius of the drop. The value of this correction is sufficiently small that the rough value of a obtained from equation (8) may be used in calculating it.

The corrected charge on the drop is, therefore, given by

$$q = \frac{6\pi d}{V} \sqrt{\frac{9\eta^3}{2\alpha g}} \left(1 + \frac{b}{pa}\right)^{-3/2} (v_E + v_g)\sqrt{v_g} \qquad (10)$$

Using the MKS system throughout, the charge q will be in coulombs, when

$b = 6.17 \times 10^{-6}$
p is pressure in cm of mercury
a is radius in meters
η is viscosity of air at 18°C
$\eta = 1.82 \times 10^{-5}$ neuton-sec/m²
$\alpha = 890$ Kg/m³ = density of Nye's watch oil
g is acceleration of gravity = 9.8 m/sec²
v_E is velocity in meters/sec
d is distance in meters
V is potential difference between plates in volts
q is charge in coulombs.

4. SETUP

Select a laboratory site for the Oil Drop Apparatus that is convenient to use and close to electrical outlets. It is preferable that work be done in a darkened room that is as free as possible from drafts and vibrations. Level the apparatus on the work surface by adjusting the legs until the spirit level, built into the cover of the oil drop chamber, indicates that the instrument is level.

Plug in the line cord and, connect a suitable source of DC power to the terminals located at the back of the cabinet.

Thread a thin wire through the oil drop hole in the center of the top metal plate and switch on the lamp. Focus the microscope on the wire. The microscope is now focused on the plane through which the oil droplets will fall. This prefocusing eliminates the need for focusing the microscope while a drop is falling. Remove the wire from the chamber.

The Oil Drop Apparatus is now ready for operation.

It is best for two people to perform each experiment, one to watch the selected droplet from beginning to end, timing the rise and fall of the droplet with a stop-watch, and the other to read and record the times indicated on the stopwatch and reset it back to zero after each observation.

It is recommended that a data table, such as that shown in the calculation section, be used for recording experimental data.

5. OPERATION

Turn on the lamp, set the polarity switch to the neutral position, and open the top alpha ray source by turning it until the indicating handle is vertical. Remove the top cover and spray a light, white petroleum oil into the chamber above the top plate. Replace the cover.

Now quickly look through the microscope. At first a diffused light will be seen which soon thins out and small individual bright spots (oil drops) appear. The ones seen first are usually too large to use and quickly fall out of the field of view. Select one of the slowest and follow its movements as the polarity of the plates is changed. Note that the microscope appears to invert the motion so that a falling drop will appear to be rising and vice versa. It is advisable to choose a drop which moves slowly when the electrical field is applied. This indicates that the charge on the drop is small, therefore probably being only a small multiple of that on the electron.

If the drop is too small, it will not travel up and down in a straight line but will waver back and forth. This is due to Brownian motion. If the drop tends to drift out of focus, move the microscope gently in or out with the rack-and-pinion adjustment but not while timing a rise or fall. If drifting is excessive, re-level the entire instrument. Practice following the drop up and down to develop the technique of observing it and controlling its motion before starting to record data.

A great many drops should be visible, especially at first. If not, the holes in the top plate may be clogged, the atomizer may not be atomizing due to fouling, or the oil may have thickened if it has been kept a very long time.

Procedure:

1. Record the barometric pressure in centimeters of mercury at the beginning and end of the experiment. Use the average value.

2. Either before or after recording the data on the oil drop the microscope must be calibrated. To do this elevate it so that it may be focused on the 0.1-mm calibration scale placed on top of the condenser. Move the scale back and forth until it is in sharp focus and determine the distance between divisions on the microscope reticle.

   After calibrating the microscope, remove one of the glass plates on the condenser and measure the distance, d, between the inner faces of the parallel plates. If preferred, this distance, d, may be measured by disassembling the condenser, measuring the thickness of the separators with a metric micrometer caliper.

3. Select a satisfactory drop and follow it up and down as long as possible while recording the time for the drop to move up (down in the microscope) a given number of divisions. Occasionally record the voltage (should be constant) and the time for the drop to move down (up in the microscope) the same number of divisions. Use the average of the latter for your calculations.

   Measure the time of rise of the drop for the same charge several times, if possible. Use the average. (A sudden change in velocity indicates that the charge on the droplet or the mass of the droplet has suddenly changed, voiding the trial.) Do this for 10 to 15 different charges, altering the charge with a radiation source, if necessary.* Sudden changes sometimes occur in the velocity of the drop moving up in the electric field due to gaining or losing one or more electrons. Calculations for the charge gained or lost may be made by using differences between the average times.

   * To change charge on droplet, set polarizing switch to neutral, and open alpha ray source to the plate gap.

Analysis of Data:

1. Calculate the velocities of rise, v_E, and the velocity of free fall, v_g, by dividing the equivalent distance (in meters) of the microscope divisions by the averaged values of the times of rise or fall (in seconds).

2. Compute the approximate radius, a, of the oil drop from equation (8). The viscosity of the air may be taken as 0.000182 poise or 0.0000182 newton-sec/m^2. (One poise is one dyne-sec/cm^2.) Use 9.8 m/sec^2 for the acceleration of gravity, g, and 890 kg/m^3 for the density of Nye's watch oil.

3. Compute the electrical charge, q, on the oil drop from equation (10). Note that most quantities in the equation remain constant during the experiment and need be computed only once.

   Calculate either the charges on the oil drop or the charges gained or lost. Using the MKS system throughout, the charge will be in coulombs. The charge, q, is always some small positive integer, n, times the value of the charge on the electron, e, that is $q = ne$.

4. By a rough inspection of the data, determine the number, n, of electrons on the drop for each charge calculated. This will be easy if the drop carried relatively few electrons, which was the reason for selecting a drop that moved upward in the electric field at a slow rate.

5. Divide the charge on the drop by the number of electrons, n, which it carried to obtain a value for the charge on the electron. These values may vary but their average should be in close agreement with the correct value of e if the experiment has been carefully performed.

6. An alternate method is to subtract the various values of ne (a) from each other and then continue subtracting these differences from each other until a common difference (which is the value of e) is found.

Supplementary Comments:

1. In using the radiation source to change the charge on the oil drop, [redacted]. Set polarity switch to neutral and open alpha ray source. (bottom one)

2. Use of a small X-ray tube for ionizing the droplet has been proposed but is not recommended because of the hazard of irradiating the observer.

3. The accepted value of the charge on the electron is 1.602×10^{-19} coulombs.

4. Two laboratory sessions may be required for this experiment. The student should read through the entire experiment first and then familiarize himself thoroughly with the apparatus and its adjustments. It may take considerable practice to get just the right size oil drop and the proper charge. Only after several trial runs should actual data be taken.

5. For the use of this apparatus in determining Avogadro's Number from Brownian Movements, see reference No. 1 in the bibliography.

6. An interesting variation of Millikan's Oil-Drop Experiment consists of suspending a charged oil drop in the electric field. A continually variable voltage source is used to adjust the potential difference to the exact value necessary to suspend the oil drop. The velocity of fall of the drop is determined as previously described.

   If we neglect the buoyant force of the atmosphere, the force of gravity equals the electric force when the particle is suspended

$$4/3\,\pi a^3 \alpha\, g = q\,\frac{V}{d}$$

   where V is the potential difference required to suspend the oil drop.

   Using the value of a given by equation (8), the value of q can be determined.

7. With the kind permission of Professor Harry F. Meiners, portions of these instructions have been freely taken from Experiment A-2, Millikan's Oil Drop Experiment, on page 302 of his manual, "Analytical Laboratory Physics," 1959 ed.

8. The condenser should be disassembled and cleaned of oil regularly. Be sure to clean the holes and the cap also.

References:

1. Hoag, J. B., and Korff, S. A., Electron and Nuclear Physics, 3rd Edition, Van Nostrand, 1949.

2. The Taylor Manual, Advanced Undergraduate Laboratory Experiments in Physics, Addison-Wesley, 1959.

3. Meiners, H.F., and Eppenstein, W., Analytical Laboratory Physics, Edwards Brothers, 1959.