MILLIKAN'S EXPERIMENT

OBJECTIVE

Carry out Millikan's experiment to onfirm the value of the elementary charge with the help of charged oil drops

SUMMARY

Between the years 1910 and 1913, *Robert Andrews Millikan* managed to measure the elementary electric charge to an unprecedented accuracy and thereby confirmed the quantum nature of charge. The experiment which now bears his name is based on measuring the quantity of charge carried by charged drops of oil, which are able to rise through the air under the influence of an electric field from a plate capacitor and descend when the field is absent. The Millikan apparatus used for this version of the experiment utilises a compact piece of equipment which is based on Millikan's design and which does not require any radioactive source.

EXPERIMENT PROCEDURE

- **Produce and select suitable oil drops and observe them in an electric field.**
- **Measure the speed with which they rise in the electric field and descend without it.**
- **Confirm the value of the elementary charge.**

REQUIRED APPARATUS

Quantity	Description	Number
1	Millikan's Apparatus (230 V, 50/60 Hz)	1018884 or
	Millikan's Apparatus (115 V, 50/60 Hz)	1018882

BASIC PRINCIPLES

Between the years 1910 and 1913, *Robert Andrews Millikan* managed to measure the elementary electric charge to an unprecedented accuracy and thereby confirmed the quantum nature of charge. He was awarded the Nobel Prize in physics for his work. The experiment which now bears his name is based on measuring the quantity of charge carried by charged drops of oil, which are able to rise through the air under the influence of an electric field from a plate capacitor and descend when the field is absent. The value he obtained for the elementary charge $e = (1.592 \pm 0.003) \cdot 10^{-19}$ C differs by only 0.6% from the accepted modern value.

The forces which act on a droplet of oil (which we shall assume to be spherical) situated in the electric field of a plate capacitor are:
the force of gravity,

(1) $$F_G = m_2 \cdot g = \frac{4}{3} \cdot \pi \cdot r_0^{\,3} \cdot \rho_2 \cdot g,$$

m_2: Mass of oil drop, r_0: Radius of oil drop, ρ_2: Density of oil, g: Acceleration due to gravity

the drop's buoyancy in air,

(2) $$F_A = \frac{4}{3} \cdot \pi \cdot r_0^{\,3} \cdot \rho_1 \cdot g,$$

ρ_1: Density of air

the force exerted by the electric field E,

(3) $$F_E = q_0 \cdot E = \frac{q_0 \cdot U}{d},$$

q_0: Charge on oil drop, U: Voltage between the plates of the capacitor, d: Separation of the capacitor plates

and Stokes' force of friction

(4) $$F_{R1,2} = 6 \cdot \pi \cdot \eta \cdot r_0 \cdot v_{1,2}.$$

η: Viscosity of air, v_1: Speed of ascent, v_2: Speed of descent

When an oil drop rises in an electric field, the equilibrium equation involves the following forces:

(5) $$F_G + F_{R1} = F_E + F_A$$

During descent the equation is as follows:

(6) $$F_G = F_{R2} + F_A.$$

This means we can find the radius of the drop and its charge:

(7) $$r_0 = \sqrt{\frac{9}{2} \cdot \frac{\eta \cdot v_2}{(\rho_2 - \rho_1) \cdot g}}$$

and

(8) $$q_0 = \frac{6 \cdot \pi \cdot \eta \cdot d \cdot (v_1 + v_2)}{U} \cdot r_0.$$

Very small radii r_0 are of the same order of magnitude as the mean free path of air molecules. This means a correction needs to be made to the Stokes' friction. The corrected radius r and charge q are then given by the following:

(9) $$r = \sqrt{r_0^{\,2} + \frac{A^2}{4}} - \frac{A}{2} \quad \text{where} \quad A = \frac{b}{p}$$

b = 82 µm•hPa = constant, p: Air pressure

(10) $$q = q_0 \cdot \left(1 + \frac{A}{r}\right)^{-1,5}.$$

The Millikan apparatus used for this version of the experiment uses a compact piece of equipment which is based on Millikan's design and which does not require any radioactive source. The charged oil drops are produced with the help of an atomiser, after which the random charge they assume is no longer affected by external influences. As in Millikan's own set-up, the droplets are introduced into the experiment chamber from above. Suitable oil drops are selected and their charge determined by observing them through a measuring microscope. For each of the drops chosen, the time to rise a certain distance in the electric field is measured, as is the time it takes to descend by the same distance with the field absent. The distance is taken to be that between two adjacent scale markings on the ocular. The polarity of the capacitor plates is selected in accordance with the sign of the charge. An alternative is to apply a field sufficient to cause the drops being measured to hover stationary in one place.
The times measured for ascent and descent of a charged drop, the voltage applied across the plates and the other parameters relevant to evaluating the results, temperature, viscosity and pressure are displayed on the touch-sensitive screen.

EVALUATION

The speeds of ascent and descent are obtained from the times t_1 and t_2 measured for the ascent or descent to occur:

$$v_{1,2} = \frac{s}{V \cdot t_{1,2}},$$

s: Distance between two selected markings on the ocular scale, V = 2: Objective magnification

From these the charge q on the oil drop is calculated using equation (10). The charges q_i determined from these measurements (Table 1) are all divided by a whole number n_i in such a way that the resulting values exhibit a minimum of variation about the mean value. The degree of spread about the mean is indicated by the standard deviation. The best estimate for elementary charge e and the standard deviation Δe can be determined from the values e_i obtained from individual measurements along with their individual deviations from the mean Δe_i (Table 1) by forming a weighted mean as below:

$$e \pm \Delta e = \frac{\sum w_i \cdot e_i}{\sum w_i} \pm \frac{1}{\sqrt{\sum w_i}} \quad \text{where} \quad w_i = \left(\frac{1}{\Delta e_i}\right)^2.$$

Using the values from Table 1, this results in:

$$e \pm \Delta e = \frac{1286}{799} \pm \frac{1}{28} = (1.61 \pm 0.04) \cdot 10^{-19}\ \text{C}.$$

The result is therefore all the more significant, the greater the number of measurements that are made, i.e. the larger the quantity of samples and the smaller the number n of differing charges on the drops. Due to measurement uncertainties, particularly in the distance between capacitor plates and readings from the microscope scale, it would be expected that $n \le 7$.

Table 1: Charges q_i measured for ten different oil drops and the value e_i determined for the elementary charge.

i	Polarity	q_i 10^{-19} C	Δq_i 10^{-19} C	n	e_i 10^{-19} C	Δe_i 10^{-19} C
1	+ / −	-11.1	0.9	-7	1.59	0.13
2	+ / −	-7.9	0.6	-5	1.58	0.12
3	+ / −	-6.2	0.4	-4	1.55	0.10
4	− / +	3.5	0.2	2	1.75	0.10
5	− / +	4.9	0.3	3	1.63	0.10
6	− / +	6.3	0.5	4	1.58	0.13
7	− / +	6.6	0.4	4	1.65	0.10
8	− / +	7.6	0.6	5	1.52	0.12
9	− / +	10.2	0.8	6	1.70	0.13
10	− / +	10.6	0.8	7	1.51	0.11

You can find technical information about the equipment at 3bscientific.com

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