II. QUANTUM PHYSICS

II.1. MILLIKAN'S EXPERIMENT

In 1911 Millikan made the first precise determination of the electron charge, proving this way the direct evidence of the electric charge discrete structure. The experimental method used by Millikan consists in direct determination of some very small oil drops charge.

1. Theory

During this work, we will make a similar experience to Millikan's one, in which we will measure the electric charge of either a smoke particle or an oil drop.

Let us consider such a particle, with a spherical shape of radius r and charge q, which is placed between the plates of a horizontal plane capacitor, to which a bias U has been applied. On this particle act the weight force G, the Arhimede force F_A, the friction (Stokes) force with the air F_S, and the electric (Coulombian) force F_e. Because the particle will uniformly move under the action of these forces, we can write:

$$\vec{G} + \vec{F}_A + \vec{F}_S + \vec{F}_e = 0 \ . \tag{1}$$

If we take into account that the direction of the particle movement is given by the direction of the electric force, depending on the particle charge, we will have the following cases:

1) for a particle positively charged, the forces diagrams at rising and falling are shown in Figures 1a, b;

2) for a particle negatively charged, the forces diagrams can be seen in Figures 1c, d.

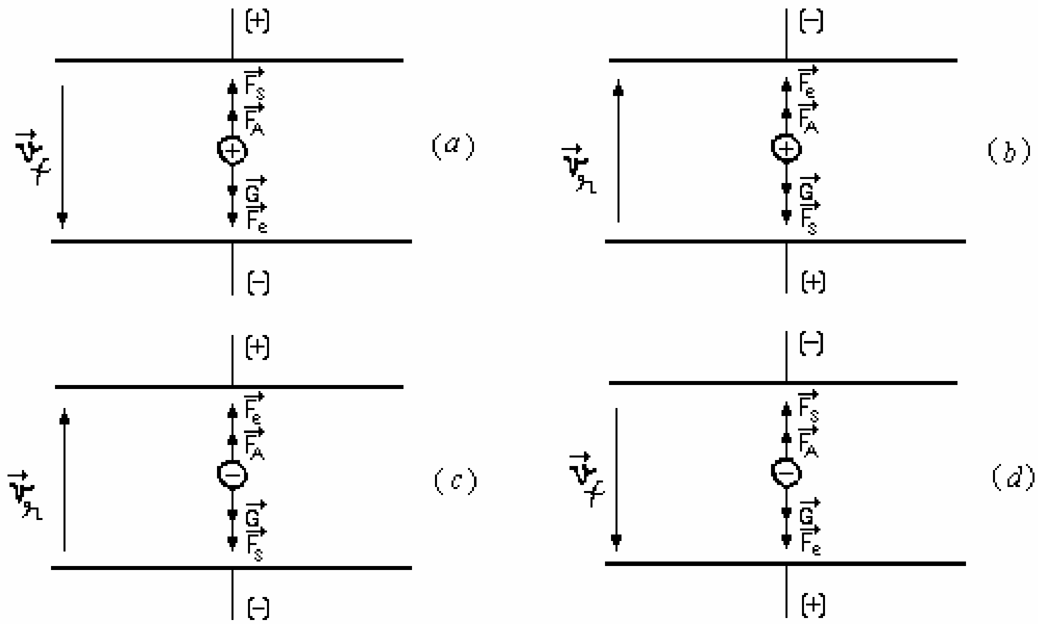

Figure 1.

By comparing these diagrams it is observed that, no matter of the sign of particle charge, the movement equations are:

- when rising:

$$F_e + F_A - G - F_{Sr} = 0, \tag{2a}$$

- when falling:

$$F_{Sf} + F_A - G - F_e = 0, \tag{2b}$$

where the rising direction of the particle was taken as positive direction for the axis OZ along which the forces act.

From the definitions of these forces we have:

- The Arhimede force :

$$F_A = \frac{4}{3}\pi r^3 \rho_a g, \tag{3a}$$

where ρ_a is the air density;

- The Stokes force:

$$F_S = 6\pi\eta v r, \tag{3b}$$

where η represents the air viscosity and v represents the particle velocity;

- The electric force:

$$F_e = qE = q\frac{U}{d}, \tag{3c}$$

where E is the electric field intensity between the capacitor plates, U is the bias applied to the capacitor and d is the distance between the plates;

- The weight force:

$$G = mg = \frac{4}{3}\pi r^3 \rho g, \tag{3d}$$

where ρ is the particle density.

Replacing these expressions in Eqs. (2a, b), we obtain:

$$qE + \frac{4}{3}\pi r^3 \rho_a g - \frac{4}{3}\pi r^3 \rho g - 6\pi\eta r v_r = 0, \tag{4a}$$

$$-qE + \frac{4}{3}\pi r^3 \rho_a g - \frac{4}{3}\pi r^3 \rho g + 6\pi\eta r v_f = 0. \tag{4b}$$

From Eqs. (4a, b) we can see that the weight force and the Arhimede force keep the same value and the same direction, too, for a given particle, the electric force keeps the same value but changes its direction, while the particle friction force with the air changes both the direction and value; the friction force suffers these changes because of its dependence to the particle movement velocity.

Eqs. (4a, b) form a system with two equations and two unknowns (q, r), from which we will determine the particle electric charge, having the following expression:

$$q = \frac{9\pi\eta^{\frac{3}{2}}}{2\sqrt{(\rho - \rho_a)g}} \frac{1}{E}(v_f + v_r)\sqrt{v_f - v_r}\,. \tag{5}$$

As the particle movement is practically uniform, we can write:

$$v_r = \frac{s}{t_r} \tag{6a}$$

and

$$v_f = \frac{s}{t_f}, \tag{6b}$$

where s is the space bounded by two landmarks (s = *const.*), which is covered by the particle during the time t_r when rising and t_f when falling.

Replacing Eqs. (6) in (5) we will find the following expression for q:

$$q = \frac{9\pi\eta^{\frac{3}{2}} s^{\frac{3}{2}}}{2\sqrt{(\rho - \rho_a)g}} \frac{d}{U}\left(\frac{1}{t_r} + \frac{1}{t_f}\right)\sqrt{\frac{1}{t_f} - \frac{1}{t_r}}, \tag{7}$$

or else:

$$q = K\frac{1}{U}\left(\frac{1}{t_r} + \frac{1}{t_f}\right)\sqrt{\frac{1}{t_f} - \frac{1}{t_r}}, \tag{8}$$

where K is a constant of the experimental set-up and has the value $K = 210.37 \cdot 10^{-19}\ \mathrm{J \cdot s^{\frac{3}{2}}}$.

2. Experimental set-up

The simplified draft of the experimental set-up is presented in Figure 2. The smoke particles will be introduced between the fittings of the plane capacitor through the channel S_1. The smoke surplus from inside will be eliminated through the channel S_2. The capacitor will be enclosed in an isolated and transparent box, which protect the smoke particles from air currents. The particle illumination will be made using the lamp L supplied at 220 V a. c. Between the capacitor plates it will be applied a d. c. bias obtained from a d. c. source. The applied bias will be measured using the voltmeter V. The switch of the capacitor polarity will be done using the switch K (position 0 – open switch, positions 1, 2 – opposite polarities).

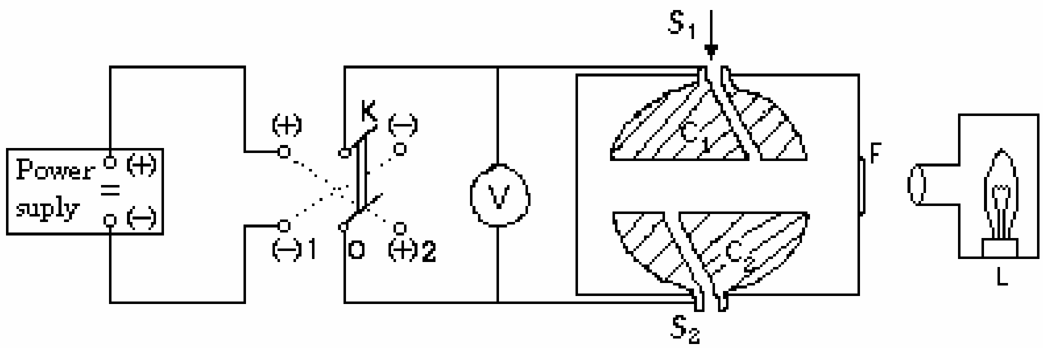

Figure 2.

The charged particles visualization is made using a microscope placed orthogonal to the illumination direction. Due to this arrangement, the light of the lamp does not enter in the microscope, but only the light diffused by the charged particles. The use of this method is due to the very small sizes of the particles that have to be studied. These will appear like some little bright stars on a dark background. The microscope ocular has two reticular horizontal threads whose images serve as landmarks for the determination of the particle velocities when rising and falling.

In addition to these, the set-up includes a stopwatch for measuring the time of the rising and falling of the charged particle between the two landmarks. This will be requested from the teaching staff.

3. Working procedure

The d. c. source will be plugged in and the illumination lamp will be switched on. The source will then be switched on and it will be checked for the absence of a bias applied on capacitor by keeping the switch K in open position (see Figure 2, position 0).

Through the existent rubber tube the smoke will be introduced inside the capacitor. The microscope ocular is fixed such that the particles have to be clearly seen in the microscope visual field. We have to wait until the air currents between the plates disappear and in the visual field only slow particles remain. At this moment, a bias is applied on the capacitor by positioning the switch K on one of the positions 1 or 2 (see Figure 2). Through the microscope it is observed that the charged particles modify their speed or even the movement direction, while the neutral particles will not notice the electric field presence.

We focus on a particle while moving, we check if by switching the bias polarity it changes its movement direction and then, using the stopwatch, we measure the intervals t_r and t_f needed for covering the distance between the two landmarks when rising and falling. While measuring, we will take into account the fact that the microscope overturns the images, so that the particles that are seen rising, actually fall. Also, due to the fact that between the landmarks the particle movement must be uniform, the upsetting of it (by switching the bias polarity) will be done outside the space between the landmarks, and the start and stop of the stopwatch will be made exactly when the particle is aligned with the landmark. We will measure the rising and falling intervals for 100 particles. The results will be put in Table 1:

Table 1

No.	U (V)	t_r (s)	t_f (s)	$\frac{1}{t_r}+\frac{1}{t_f}$ (1/s)	$\sqrt{\frac{1}{t_f}-\frac{1}{t_r}}$ ($s^{-1/2}$)	q (C)

4. Experimental data processing

The data from all the columns of the Table 1 are filled in and the charge of each particle is computed using the relation (8). With the obtained data we will make a graphic of the particles distribution on the different charge values. A horizontal axis divided on a convenient scale is chosen and above the scale it is drawn a point for each value of each charge q. If two values are equal the points will be drawn distinctly one above the other (see Figure 3).

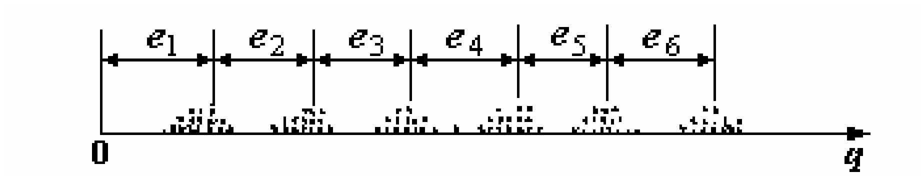

Figure 3

We notice that more groups of points appear. It will be estimated and noted with a vertical bar the place where the weight centre of each group is situated. These should hit exactly the multiples of the electron charge. The intervals e_1, e_2, ..., between the drawn bars are written. The electron charge is obtained by making the average of these values:

$$e = \frac{1}{n}\sum_{i=1}^{n} e_i \,, \tag{9}$$

where n represents the number of the groups. The standard error is then:

$$\sigma_e = \sqrt{\frac{1}{n(n-1)} \cdot \sum_{i=1}^{n} (e_i - e)^2} \,. \tag{10}$$