The Electrical Charge on Sprayed Oil Drop

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Ken MIYAGI

In order to determine electrical charge on sprayed oil drop, using Millikan's oil drop method, fall time t_d and rise time t_u of oil drops were measured and plotted.

The measurement was done for five kinds of oil; sewing-machine oil, baby oil, covus oil, tung oil, and olive oil. The results showed that the value of electrical charge on drop of olive oil was largest, sewing-machine oil's smallest, and the value of electrical charge on the oil drop was larger for the oil drop with larger coefficient of viscosity. It was observed that some of drops of olive oil had positive or negative electrical charge not smaller than 100 e, and that no drop of sewing-machine oil had charge larger than 4 e.

1. Introduction

In measurement of the elementary charge, the electrical charge of electron, Millikan's oil drop method is usually used. In the method, electric field strength should be changed according to kind of oil used. This is based on a reason that the value of electrical charge on sparyed oil drop depends on kind of oil used.

In this experiment, Millikan's oil drop method was used not to determine accurate value of the elementary charge, but to measure rough value of electrical charge on drops of five kinds of oil, sewing-machine oil, baby oil, covus oil, tung oil, and olive oil, as they are sprayed from an atomizer. So, in the measurement, X-ray or radioactive substances to change electrical charge on drops were not needed.

2. Experimental Procedures

Two thick brass plates, 5 cm square, were used as electrodes, and one of these, top plate, had a pin hole. These plates were separated by two bake-lite strips of 0.51 cm in thickness. Oil was sprayed by a hand air pump, and brought into a paper cylinder mounted on the top plate through a vinyle pipe of about 80 cm in length (see Fig. 1).

First, the suitable voltages, which made possible measuring of rise time of oil drops with large electrical charge, were determined. The voltages were 1,000 volts for sewing-machine oil, 500

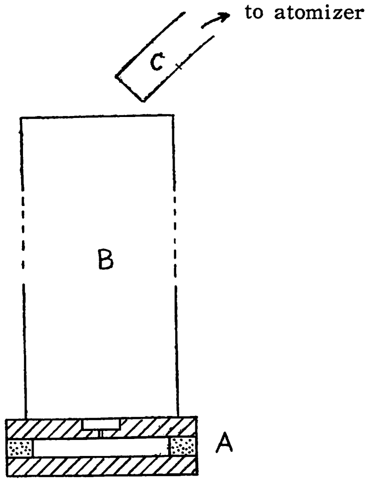

Fig. 1. Diagram of Apparatus
A: Electrodes
B: Paper Cylinder
C: Vinyle-pine

volts for baby oil, 100 volts for covus oil, 60 volts for tung oil, and 20 volts for olive oil. Under the said voltage, fall and rise times of many drops of the same oil located between the electrodes were measured by repeating oil spraying, and electric field direction was altered for opposite charge. .The same measurements were carried out for the five kinds of oil.

Next, the higher voltages, which were suitable for making oil drops with small electrical charge move upward, were determined. These voltages were 2,000 volts for sewing-machine oil and baby oil, 1,000 volts for covus oil and olive oil and 1,300 volts for tung oil. The measurements, under these voltages, were made for the five kinds of oil in the same manner. The measurements of electrical charge on drops were made at temperature between 15.2°C and 13.3°C.

Besides the measuring the value of electrical charge on drops, the number of the positively charged oil drops was compared with that of the negatively charged oil drops within the visual field of the microscope. By repeating oil spraying, the observations were repeated several times for five different oils respectively.

Density, surface tension, and coefficient of viscosity of the five kinds of oil were measured in order to see how these properties were related with the value of electrical charge on drops of these oils. Baume's hydrometer, Du Nouy tensiometer, and coaxial rotating-cylinder viscosimeter were used for measuring density, surface tension, and viscosity, respectively. The results of measurements are shown in Table 2.

3. Results and Discussion

According to Stoke's law, the following relationship holds for the free fall of a small oil drop with constant velocity v_d;

$$\frac{4}{3}\pi a^3(\sigma-\rho)g=6\pi\eta a v_d^{(1)}, \qquad (1)$$

where a is radius of the drop, σ is density of oil, ρ is air density, and η is coefficient of viscosity of the air.

When a suitable voltage is applied to the electrodes, an oil drop located between the electrodes moves upward with a constant velocity v_u. Thus

$$\frac{4}{3}\pi a^3(\sigma-\rho)g+6\pi\eta a v_u=qE, \qquad (2)$$

where q is electrical charge on the oil drop and E is electric field strength.

From equation (1) and (2)

$$6\pi\eta a(v_d+v_u)=qE,$$

$$q=\frac{6\pi\eta a}{E}(v_d+v_u). \qquad (3)$$

From equation (1)

$$a=\frac{3}{\sqrt{2}}\frac{\eta^{1/2}v_d^{1/2}}{(\sigma-\rho)^{1/2}g^{1/2}}. \quad (4)$$

Fall and rise velocities are

$$v_d=\frac{l}{t_d} \text{ and } v_u=\frac{l}{t_u}, \quad (5)$$

where l is the distance that the drop falls and rises.

From equations (3), (4) and (5)

$$q=9\sqrt{2}\frac{\pi\eta^{3/2}l^{3/2}}{E(\sigma-\rho)^{1/2}g^{1/2}}\left(\frac{1}{t_d}\right)^{1/2}\left(\frac{1}{t_d}+\frac{1}{t_u}\right),$$

or

$$q=K\left(\frac{1}{t_d}\right)^{1/2}\left(\frac{1}{t_d}+\frac{1}{t_u}\right).$$

Finally,

$$t_u=\frac{\frac{K}{q}\cdot t_d}{(t_d)^{3/2}-\frac{K}{q}}, \quad (6)$$

$$K=9\sqrt{2}\frac{\pi\eta^{3/2}l^{3/2}}{E(\sigma-\rho)^{1/2}g^{1/2}}, \quad (7)$$

$$E=\frac{V}{300d} \text{ e. s. u.}, \quad (8)$$

where V is applied voltages in volt and d is distance in centimeter between the electrodes. Equation (6) represents an algebraical curve with two asymptotes $t_u=0$
and

$$t_d=\left(\frac{K}{q}\right)^{2/3}. \quad (9)$$

Thus, if E is constant, plotted points of many oil drops with the same electrical charge and different mass form the curve (see Fig. 2, 3, 4, 5 and 6). One of the asymptotes, which is represented by equation (9), depends on E or V and q. The results of the calculation are shown in Table 1. The values used in calculation of $(K/q)^{2/3}$ are as follows:

$\eta=1.79\times10^{-4}$ gr./cm sec

$g=980$ cm/sec^2

$l=0.050$ cm

$\rho=0.0012$ gr./c.c.

σ=0.865 gr./c.c. for sewing-machine oil,
0.885 gr./c.c. for baby oil,
0.890 gr./c.c. for covus oil,
0.945 gr./c.c. for tung oil,
0.950 gr./c.c. for olive oil,
q=e, 2e, 3e,……, 200e,
e=4.80×10^{-10} e. s. u..

Table I. The Value of $\left(\frac{K}{q}\right)^{2/3}$

	Sewing-machine oil		Baby oil		Covus oil		Tung oil		Olive oil	
q \ V	2,000V	1,000V	2,000V	500V	1,000V	100V	1,300V	60V	1,000V	20V
1 e	3.25	5.16	3.23	8.14	5.11	23.8	4.21	32.7	4.98	67.6
2 e	2.05	3.25	2.04	5.13	3.22	15.0	2.66	20.6	3.14	42.6
3 e	1.56	2.48	1.56	3.92	2.46	11.4	2.02	15.7	2.40	32.5
4 e	1.29	2.05	1.29	3.25	2.03	9.45	1.67	13.0	1.98	26.8
5 e	1.11	1.76	1.11	2.78	1.75	8.13	1.44	11.2	1.70	23.1
6 e	0.98	1.56	0.98	2.47	1.55	7.21	1.28	9.92	1.51	20.5
7 e	0.89	1.41	0.89	2.22	1.40	6.49	1.15	8.94	1.36	18.5
8 e	0.81	1.29	0.81	2.04	1.28	5.94	1.05	8.19	1.24	16.9
9 e	0.75	1.19	0.75	1.88	1.18	5.50	0.97	7.57	1.15	15.6
10 e	0.70	1.11	0.70	1.75	1.10	5.11	0.91	7.04	1.07	14.6
15 e				1.34		3.90		5.38		11.1
20 e				1.11		3.23		4.48		9.20
30 e						2.47		3.39		7.70
40 e						2.04		2.79		5.78
50 e						1.76		2.41		4.98
60 e								2.14		4.42
70 e								1.93		3.99
80 e								1.76		3.65
90 e								1.64		3.38
100 e								1.49		3.14
150 e								1.16		2.39
200 e								0.96		1.98

Some of asympototes are represented by broken lines in Fig. 2, 3, 4, 5 and 6. The part A's of Fig. 2, 3, 4, 5 and 6 show that the smallest charge on drop of the five different oil is equal to the elementary charge e.

In the measurement of smaller charge, the upward motions of most of tung and olive oil drops were too fast for t_u to be measured, but, for baby and covus oil drops, only a few were in such rapid motions, and none for sewing-machine oil drops. The part B's of Fig. 2, 3, 4, 5 and 6 show the results of measurement of larger charge on drops. The figures show that the amount of charge on drops depends on oil used, charge on drop of olive oil being the largest. Some of drops

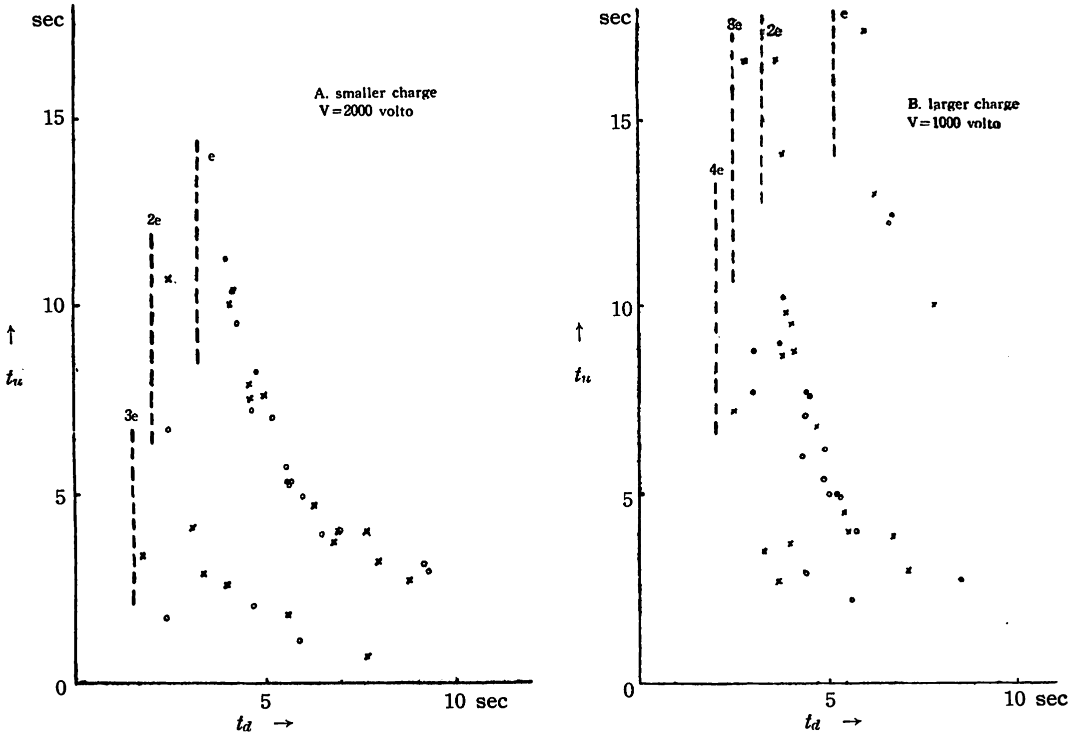

Fig. 2. Fall time and rise time of drops of sewing-machine oil.
○: Positively charged drops. ×: Negatively charged drops. Broken lines: Asymptotes.

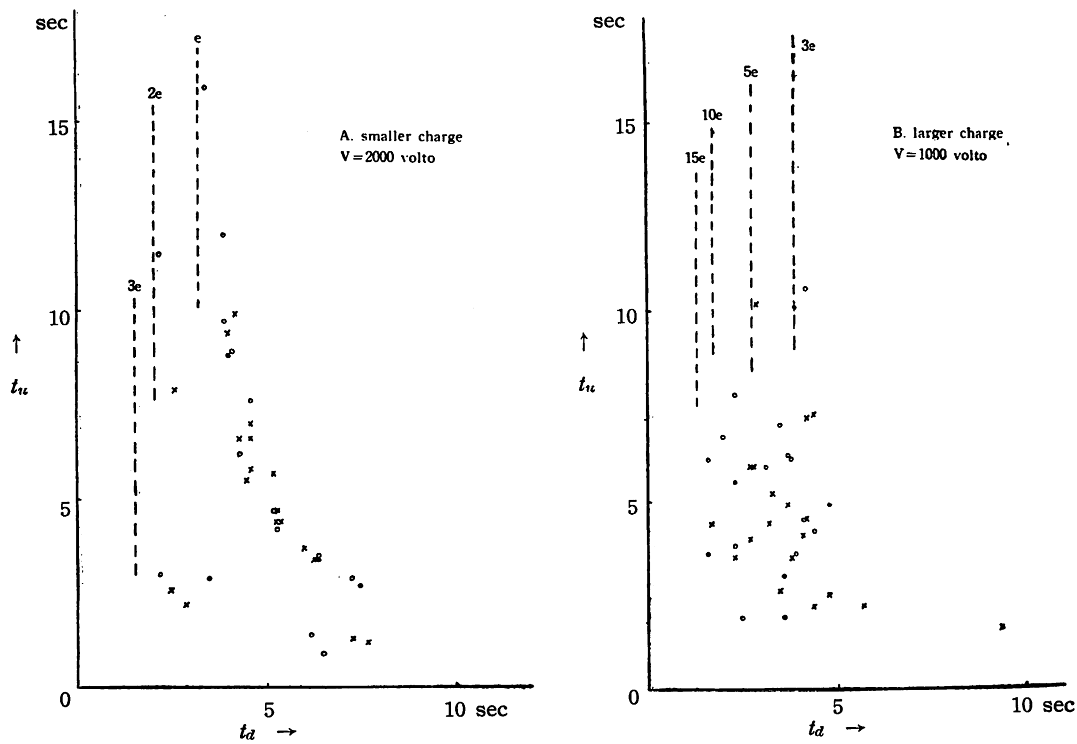

Fig 3.. Fall time and rise time of drops of baby oil.
○: Positively charged drops. ×: Negatively charged drops. Broken lines: Asymptotes.

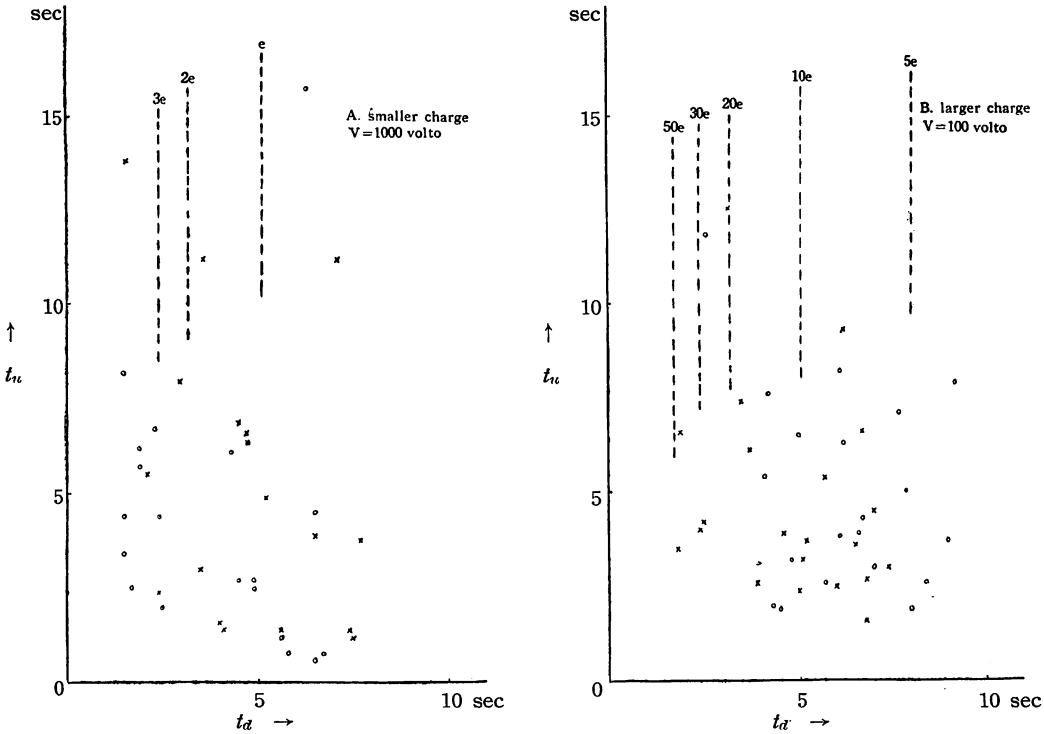

Fig. 4. Fall time and rise time of drops of covus oil.
○: Positively charged drops. ×: Negatively charged drops. Broken lines: Asymptotes.

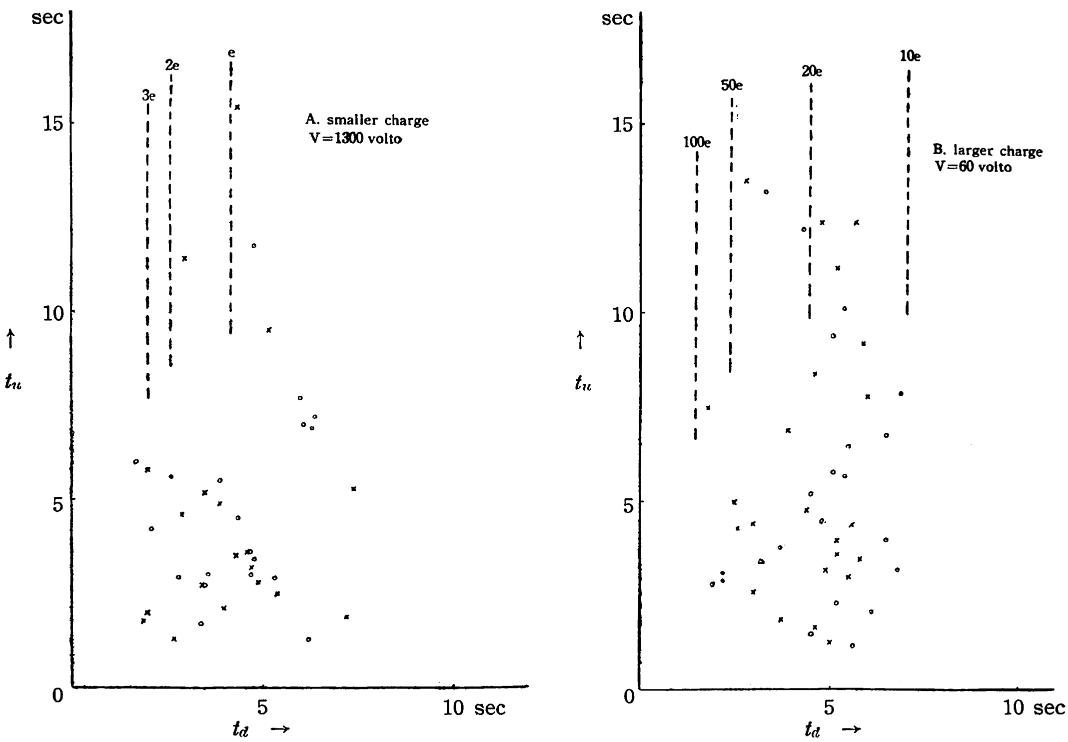

Fig. 5. Fall time and rise time of drops of Tung oil.
○: Positively charged drops. ×: Negatively charged drops. Broken lines: Asymptotes.

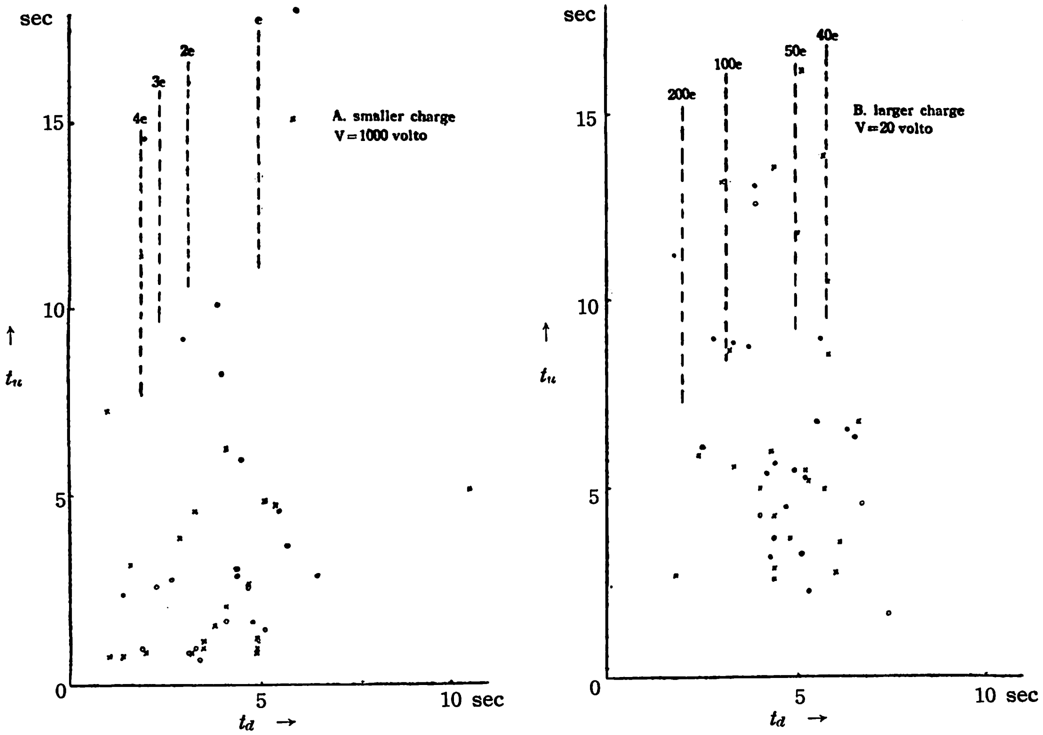

Fig. 6. Fall time and rise time of drops of olive oil.
○: Positively charged drops. ×: Negatively charged drops. Broken lines: Asymptotes.

of the oil have positive or negative charge not smaller than 100 e, but no drop of sewing-machine oil has charge larger than 4 e. The magnitudes of the electrical charge on oil drops were in the order of olive oil, tung oil, covus oil, baby oil, and sewing-machine oil.

Table II

	Density (at 18°C) gr./c.c.	Surface Tension (at 12.2°C) dyn/cm	Coefficient of Viscosity (at 19°C) gr./cm, sec
Sewing-machine oil	0.862	41.8	0.24
Baby oil	0.881	44.9	0.25
Covus oil	0.887	48.0	0.41
Tung oil	0.941	50.0	0.79
Olive oil	0.947	46.4	0.82

In the measurement, voltage applied to electrodes was made low enough so that no drop moved too fast upward to be measured. The value of electrical charge on the oil drop was larger for the oil with larger coefficient of viscosity.

The fact shows that larger values of electrical charge on sprayed oil drops depend on kind of oils used. On the other hand, it was observed that the number of the positively charged drops was approximately equal to that of the negatively charged drops. These facts might shed some light on the mechanism of charging of the drops. It is usually said that charging of oil drops, as the oil is sprayed from an atomizer, is due to friction[2]; but, from the results shown above, it might rather be considered that the charge on oil drops results from the rupture of oil into drops.

References

1) J. Barton Hang; Electron and Muclear Physics.
2) R. A. Millikan; Electron (+ and −).