Elementary charge and Millikan experiment

LEP 5.1.01

Related topics

Electric field, viscosity, Stoke's law, droplet method, electron charge.

Principle and task

Charged oil droplets subjected to an electric field and to gravity between the plates of a capacitor are accelerated by application of a voltage. The elementary charge is determined from the velocities in the direction of gravity and in the opposite direction.

Equipment

Millikan apparatus	09070.00	1
Multi-range meter w. overl. prot.	07021.01	1
Power supply, 0…600 VDC	13672.93	1
Stage micrometer, 1 mm - 100 div.	62046.00	1
Stop watch, interruption type	03076.01	2
Cover glasses 18×18 mm, 50 pcs.	64685.00	1
Commutator switch	06034.03	1
Tripod base -PASS-	02002.55	1
Stand tube	02060.00	1
Connecting cord, 250 mm, black	07360.05	1
Connecting cord, 750 mm, red	07362.01	2
Connecting cord, 750 mm, blue	07362.04	2
Connecting cord, 750 mm, black	07362.05	3

Optional accessories:

Radioactive source, Am-241, 74 kBq	09047.51	1
Circular level	02122.00	1
FlexCam Scientific	88031.93	1

Problems

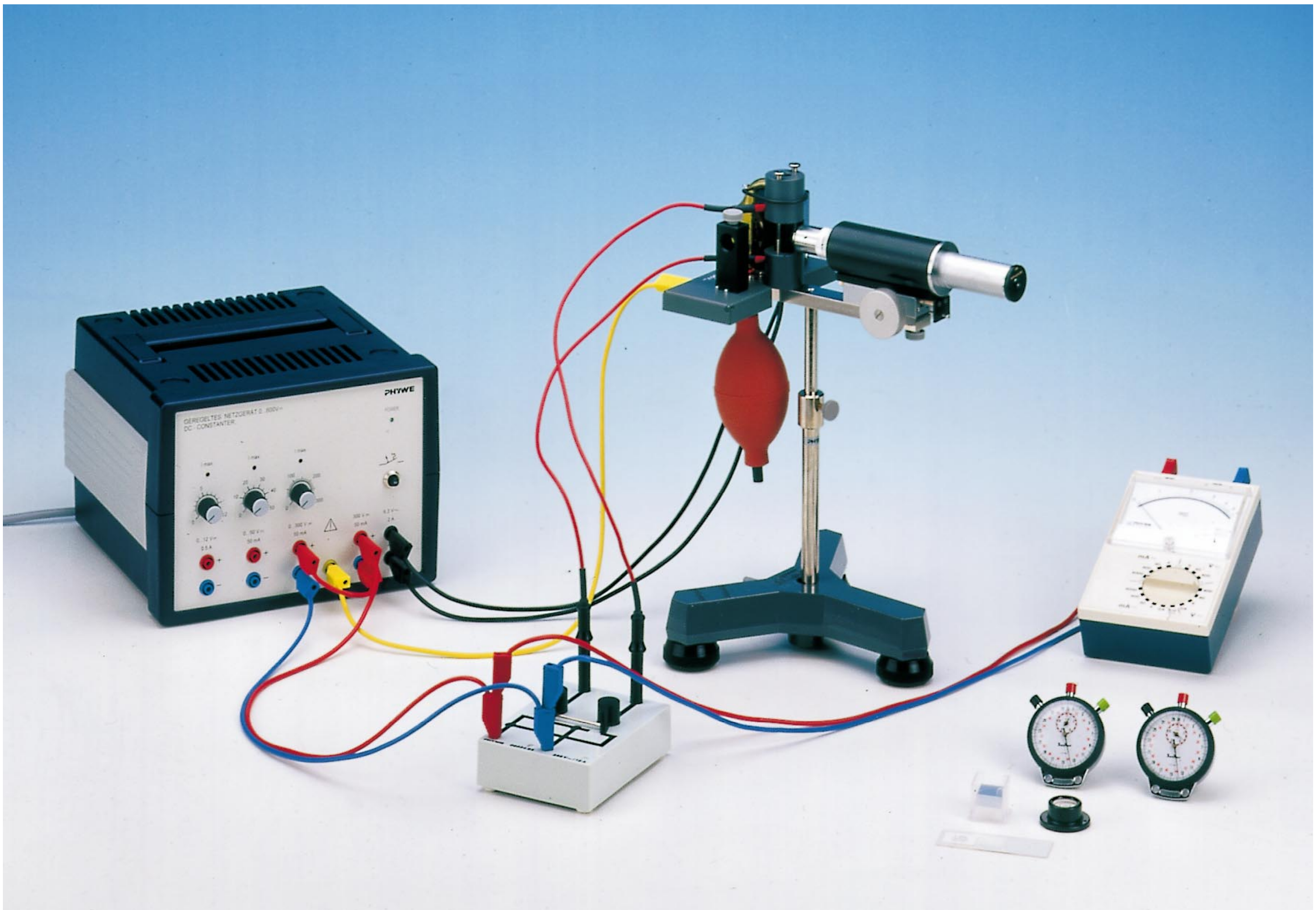
1. Measurement of the rise and fall times of oil droplets with various charges at different voltages.
2. Determination of the radii and the charge of the droplets.

Set-up and procedure

The experimental set up is as shown in Fig. 1. The power unit supplies the necessary voltages for the Millikan apparatus. The lighting system is connected to the 6.3 V a.c. sockets.

First calibrate the eyepiece micrometer with a stage micrometer. By connecting the fixed (300 V d.c.) and the variable (0 to 300 V d.c.) outputs in series, a voltage supply of more than 300 V d.c. can be obtained. The commutator switch will be used to invert the polarity of the capacitor.

Fig. 1: Experimental set up for determining the elementary charge with the Millikan apparatus.



– Set the capacitor voltage to a value between 300 V and 500 V.
– Blow in the oil droplets.
– Select an oil droplet and by operating the commutator switch move the droplet between the highest and lowest graduations on the eyepiece micrometer. Correct the focusing of the microscope if necessary.

Note the following criteria when selecting the droplet:
– The droplet must not move too fast, then it has a small charge (it should need ca. 1…3 s for the way of 30 div.)
– The droplet must not move too slowly and should not exhibit any sqaying movements. Increase the capacitor voltage if required.
– Sum together some rise times using the first stopwatch.
– Sum together some fall times using the second stopwatch.
– The added times should be greater than 5 s in both cases.

Theory and evaluation

The falling and rising movement of a charged oil droplet in the electric field of the capacitor is obverserved and the velocities are determined.

Velocity falling in the electric field	υ_1
Velocity rising in the electric field	υ_2
Capacitor voltage	U
Charge on the droplets	$Q = n \cdot e$
Radius of the droplets	r
Capacitor interelectrode distance	d = 2.5 mm ± 0.01 mm
Density of the silicone oil	$\rho_1 = 1.03 \cdot 10^3$ kg m^{-3}
Viscosity of air	$\eta = 1.82 \cdot 10^{-5}$ kg (m·s)$^{-1}$
Gravitational acceleration	g = 9.81 ms^{-2}
Density of air	ρ_2 = 1,293 kg m^{-3}

The force F experienced by a sphere of radius r and velocity υ in a viscous fluid of viscosity η, is:

$$F = 6\,\pi r \eta \upsilon \text{ (Stockes' law).} \quad (1)$$

The sheric droplet of mass m, volume V and density ρ_1 is located in the earth's gravitational field.

$$F = m \cdot g = \rho_1 \cdot V \cdot g \quad (2)$$

Force of buoyancy is given by

$$F = \rho_2 \cdot V \cdot g \quad (3)$$

The Force of the electrical field is given by

$$F = Q \cdot E = Q \cdot \frac{U}{d} \quad (4)$$

From the sum of the forces affecting a charged particle, the fall and rise velocities of the droplets are obtained.

$$\upsilon_1 = \frac{1}{6\pi r\,\eta}\left(QE + \frac{4}{3}\,\pi r^3 g\,(\rho_1 - \rho_2)\right) \quad (5)$$

$$\upsilon_2 = \frac{1}{6\pi r\,\eta}\left(Q \cdot E - \frac{4}{3}\,\pi r^3 g\,(\rho_1 - \rho_2)\right) \quad (6)$$

Substraction or addition of these equations gives the radius and the charge of the droplet.
with

$$Q = C_1 \cdot \frac{\upsilon_1 + \upsilon_2}{U}\sqrt{\upsilon_1 - \upsilon_2} \quad (7)$$

$$C_1 = \frac{9}{2}\,\pi\, d \cdot \sqrt{\frac{\eta^3}{g\,(\rho_1 - \rho_2)}}$$

$$C_1 = 2.73 \cdot 10^{-11} \text{ kg m (m} \cdot \text{s)}^{-1/2}$$

with

$$r = C_2 \cdot \sqrt{\upsilon_1 - \upsilon_2} \quad (8)$$

$$C_2 = \frac{3}{2} \cdot \sqrt{\frac{\eta}{g\,(\rho_1 - \rho_2)}}$$

$$C_2 = 6.37 \cdot 10^{-5} \text{ (m} \cdot \text{s)}^{1/2}$$

Calibrating of the eyepiece micrometer:
Scale with 30 div. = 0.89 mm

The measured falling and rising times of 20 droplets are given in table 1.

Fig. 2 shows that the charge of the droplets have certain values which are multiples of the elementary charge e

$$Q = n \cdot e$$

As a mean value, the elementary charge is obtained as

$$e = 1.68 \cdot 10^{-19} \text{ As}$$

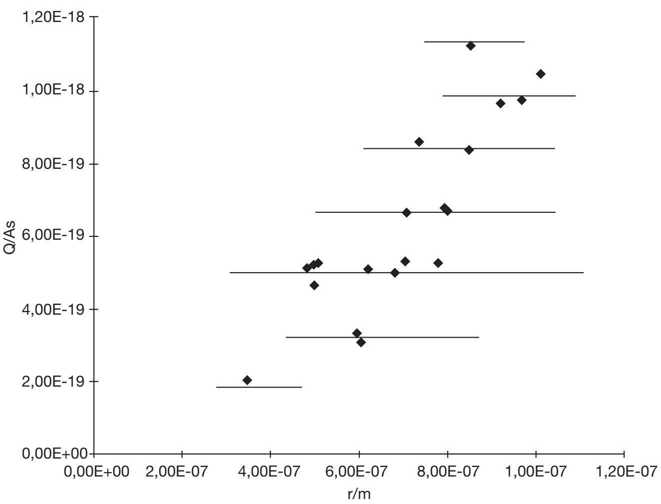


Fig. 2: Measurements on various droplets for determining the elementary charge by the Millikan method.

U/V	t_1/s	s_1/div.	t_2/s	s_2/div.	s_1/mm	s_2/mm	υ_1/(m/s)	υ_2/(m/s)	$(\upsilon_1-\upsilon_2)$/(m/s)	r/m	Q/As	n	e/As
300	9.6	150	13.5	150	4.45	4.45	4.64E-04	3.30E-04	1.34E-04	7.37E-07	8.54E-19	5	1.71E-19
300	7.0	90	11.2	120	2.67	3.56	3.81E-04	3.18E-04	6.36E-05	5.08E-07	5.19E-19	3	1.73E-19
300	5.8	90	7.1	60	2.67	1.78	4.60E-04	2.51E-04	2.10E-04	9.22E-07	9.57E-19	6	1.60E-19
300	7.4	90	8.8	60	2.67	1.78	3.61E-04	2.02E-04	1.59E-04	8.02E-07	6.59E-19	4	1.65E-19
300	6.9	90	8.2	90	2.67	2.67	3.87E-04	3.26E-04	6.13E-05	4.99E-07	5.19E-19	3	1.73E-19
300	5.6	90	8.0	60	2.67	1.78	4.77E-04	2.23E-04	2.54E-04	1.02E-06	1.04E-18	6	1.73E-19
400	6.9	90	9.8	90	2.67	2.67	3.87E-04	2.72E-04	1.15E-04	6.82E-07	4.92E-19	3	1.64E-19
400	6.4	90	8.3	90	2.67	2.67	4.17E-04	3.22E-04	9.55E-05	6.23E-07	5.04E-19	3	1.68E-19
400	5.0	90	5.0	60	2.67	1.78	5.34E-04	3.56E-04	1.78E-04	8.50E-07	8.28E-19	5	1.66E-19
400	7.0	120	7.9	120	3.56	3.56	5.09E-04	4.51E-04	5.79E-05	4.85E-07	5.09E-19	3	1.70E-19
400	6.0	60	8.5	60	1.78	1.78	2.97E-04	2.09E-04	8.73E-05	5.95E-07	3.30E-19	2	1.65E-19
400	5.5	90	7.4	90	2.67	2.67	4.85E-04	3.61E-04	1.25E-04	7.11E-07	6.59E-19	4	1.65E-19
400	4.7	60	7.8	60	1.78	1.78	3.79E-04	2.28E-04	1.51E-04	7.82E-07	5.19E-19	3	1.73E-19
400	5.2	120	10.6	180	3.56	5.34	6.85E-04	5.04E-04	1.81E-04	8.57E-07	1.11E-18	7	1.59E-19
400	6.5	60	9.7	60	1.78	1.78	2.74E-04	1.84E-04	9.03E-05	6.05E-07	3.03E-19	2	1.52E-19
500	6.4	120	7.2	120	3.56	3.56	5.56E-04	4.94E-04	6.18E-05	5.01E-07	4.61E-19	3	1.54E-19
500	5.5	90	9.8	120	2.67	3.56	4.85E-04	3.63E-04	1.22E-04	7.04E-07	5.23E-19	3	1.74E-19
500	5.2	60	5.7	60	1.78	1.78	3.42E-04	3.12E-04	3.00E-05	3.49E-07	2.00E-19	1	2.00E-19
500	6.4	120	8.9	120	3.56	3.56	5.56E-04	4.00E-04	1.56E-04	7.96E-07	6.67E-19	4	1.67E-19
500	5.2	120	5.9	90	3.56	2.67	6.85E-04	4.53E-04	2.32E-04	9.70E-07	9.67E-19	6	1.61E-19

Table 1: Measurements on various droplets for determining the elementary charge by the Millikan method. t_1 and t_2 are the fall and rise times of the droplets.

Alteration of the charge

Using a radioactive source (e.g. Am-241, 74 kBq) the charge of the oil droplets in the capacitor chamber can be altered. The radioactive source has to be positioned in front of the mica window of the Millikan Unit which is transparent for α particles.

Observation with Video camera

A video camera, which is used in place of the eye, can be used for the demonstration of the movement of the droplet. The time measurements of the moving droplet becomes much easier, and will even be more accurate, due to the better visibility. The intensity of the light from the illumination device is sufficient for observation with a video camera.