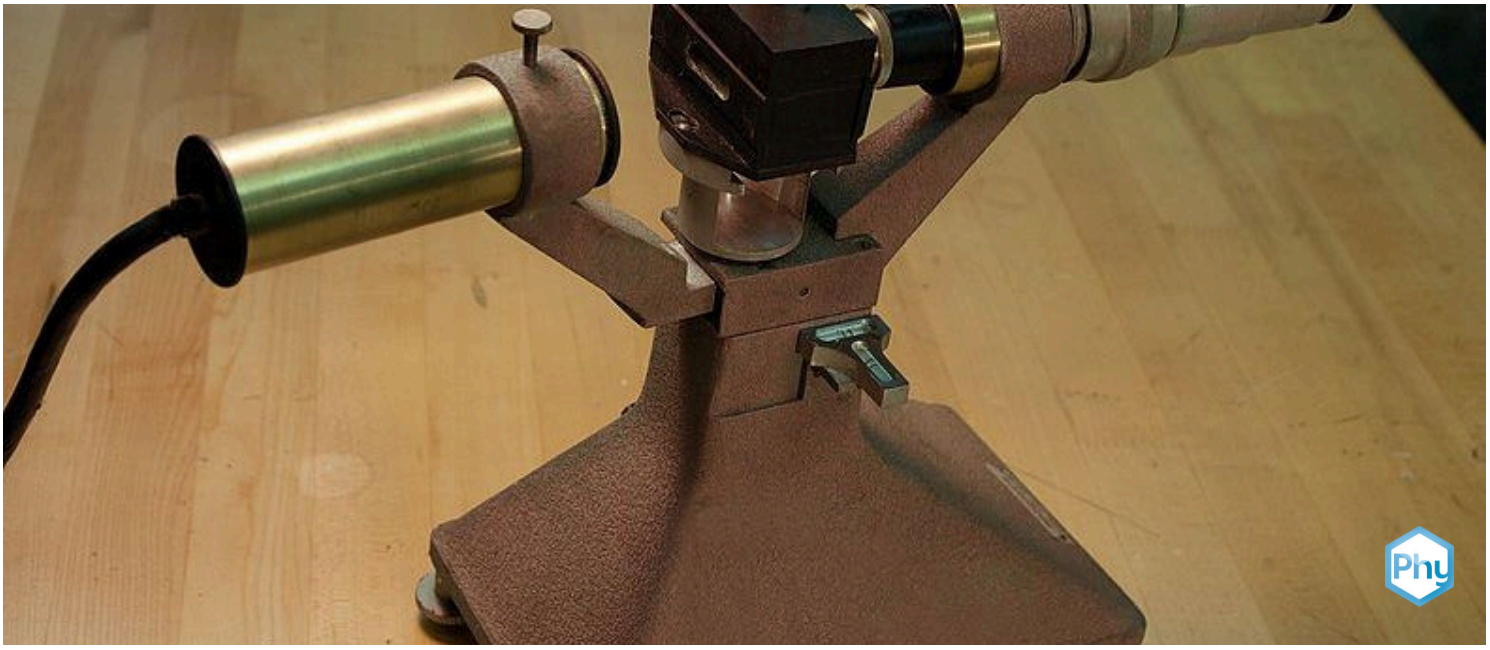
Elementary charge and Millikan experiment



Physics > Electricity & Magnetism > Electrostatics & electric field

Physics > Modern Physics > Quantum physics

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

This content can also be found online at:

http://localhost:1337/c/5f0ec8ecb6127b00030447e6

PHYWE

General information

Application

PHYWE

Oil drop experiment apparatus

In 1909, the oil drop experiment was performed by Robert Millikan to determine the charge of an electron. By comparing applied electric force with changes in the motion of the oil drops, the electric charge on each drop could be determined. This led to the finding that all of the drops had charges that were simple multiples of a single number, the fundamental charge of the electron, which is denoted by *e* or *q*.

$$e = 1.602.10^{-19} C$$

This method offered convincing proof that electric charge exists in basic natural units.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Other information (1/2)

PHYWE

Prior knowledge

An elementary charge is the electrical charge carried by a single electron or proton. Atoms of matter are electrically neutral because their nuclei contain the same number of protons as there are electrons surrounding the nuclei. Charge thus exists in natural units equal to the charge of an electron or a proton, a fundamental physical constant.

Scientific principle

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.

Other information (2/2)

PHYWE

Learning objective

To study the electric charge carried by a particle by measuring the force experienced by the particle in an electric field of known strength.

Tasks

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.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Safety instructions

PHYWE

For this experiment the general instructions for safe experimentation in science lessons apply.

Use suitable protective measures as electrical currents can be dangerous for humans.

Theory (1/3)

PHYWE

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

$$F = 6\pi r\eta v \qquad \text{(Stockes' law).}$$

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

$$F = m \cdot g = \rho_1 \cdot V \cdot g$$

Force of buoyancy is given by

$$F = \rho_2 \cdot V \cdot g$$

The force of the electrical field is given by

$$F = Q.E = Q.\frac{U}{d}$$

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Theory (2/3)

From the sum of the forces affecting a charged particle, the fall and rise velocities of the droplets, v_1 and v_2 respectively, are obtained.

$$v_1 = \frac{1}{6\pi r\eta(QE+\frac{4}{3}\pi r^3 g(\rho_1-\rho_2))}$$

$$v_2 = \frac{1}{6\pi r\eta(QE-\frac{4}{3}\pi r^3 g(\rho_1-\rho_2))}$$

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

Theory (3/3)

With

$$Q = C_1(\frac{v_1+v_2}{U})\sqrt{v_1-v_2}$$

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

$$r = C_2\sqrt{v_1-v_2}$$

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

The charge of the droplets have certain values which are multiples of the elementary charge *e*

$$Q = n.e$$

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

Equipment

Position	Material	Item No.	Quantity
1	Millikan apparatus	09070-00	1
2	PHYWE Power supply, regulated DC: 0...12 V, 0,5 A; 0...650 V, 50 mA / AC: 6,3 V, 2 A	13672-93	1
3	Digital multimeter, 600V AC/DC, 10A AC/DC, 20 MΩ, 200 µF, 20 kHz, −20°C… 760°C	07122-00	1
4	Digital stopwatch, 24 h, 1/100 s and 1 s	24025-00	2
5	PHYWE Object micrometer on glass plate, 1 mm in 100 parts	62171-19	1
6	Cover glasses 18x18 mm, 50 pcs	64685-00	1
7	Circular level, d = 36 mm	02123-00	1
8	Tripod base PHYWE	02002-55	1
9	Stand tube	02060-00	1
10	Safety connecting cable, 32A, l = 50cm, red	07336-01	1
11	Safety connecting cable, 32A, l = 100cm, red	07337-01	2
12	Safety connecting cable, 32A, l = 100cm, blue	07337-04	2
13	Connecting cord, 32 A, 750 mm, black	07362-05	2
14	Connecting cord, 32 A, 750 mm, green-yellow	07362-15	1
15	Commutator switch	06006-00	1

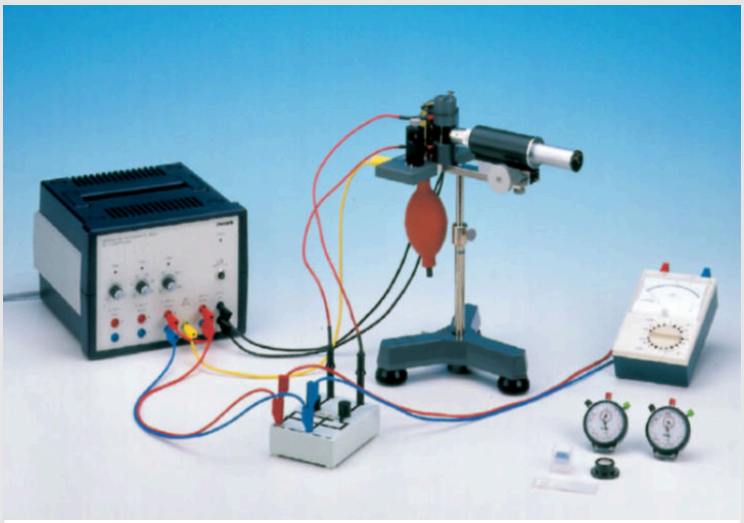
PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de

PHYWE

Setup and procedure

Setup

PHYWE



Experimental setup

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 300V 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.

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

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Procedure (1/2)

PHYWE

- 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.
- Measure falling and rising times of 20 droplets

Procedure (2/2)

PHYWE

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 swaying 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 5s in both cases.

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Evaluation (1/4)

PHYWE

From the known constant values, C_1 and C_2 are determined:

$C_1 = 2.73.10^{-11} kgm(ms)^{-1/2}$

$C_2 = 6.37.10^{-5}(ms)^{1/2}$

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

Parameters	Values
Capacitor interelectrode distance	$d = (2.5 \pm 0.01)mm$
Density of the silicone oil	$\rho_1 = 1.03.10^3 kg/m^3$
Viscosity of air	$\eta = 1.82.10^{-5} kg/(ms)$
Gravitational acceleration	$g = 9.81 m/s^2$
Density of air	$\rho_2 = 1.293 kg/m^3$

The constant values during the experiment

Evaluation (2/4)

PHYWE

$\frac{U}{V}$	$\frac{t_1}{s}$	$\frac{s_1}{div}$	$\frac{t_2}{s}$	$\frac{s_2}{div}$	$\frac{s_1}{mm}$	$\frac{s_2}{mm}$	$\frac{v_1}{m/s}10^{-4}$	$\frac{v_2}{m/s}10^{-4}$	$\frac{r}{m}10^{-7}$	$\frac{Q}{As}10^{-19}$	n	$\frac{e}{As}10^{-19}$
300	9.6	150	13.5	150	4.45	4.45	4.64	3.30	7.37	8.54	5	1.71
400	6.9	90	9.8	90	2.67	2.67	3.87	2.72	6.82	4.92	3	1.64
500	6.4	120	7.2	120	3.56	3.56	5.56	4,94	5.01	4.61	3	1.54

$\bar{e} = 1.68.10^{-19} As$

Measurements on various droplets for determining the elementary charge by the Millikan method

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

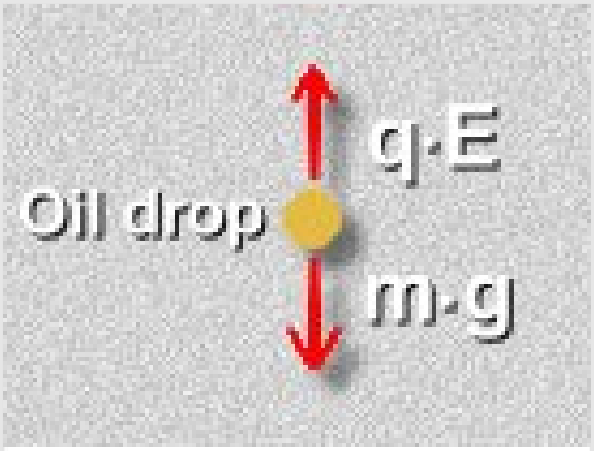
Evaluation (3/4)

PHYWE

When do the oil drops move upwards?

- ○ The electric force is smaller for them than the gravitational force
- ○ The electric force is equal as the gravitational force
- ○ The electric force is greater for them than the gravitational force

Check



The forces on an oil drop

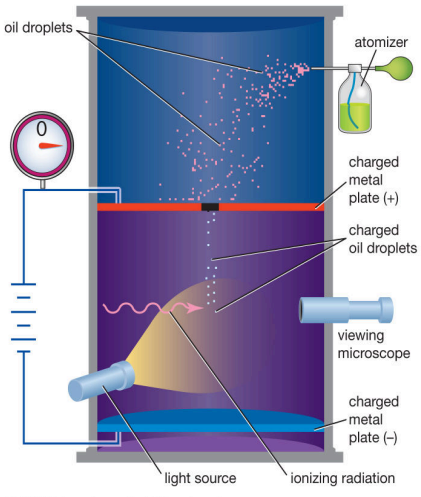
Evaluation (4/4)

PHYWE

What does oil drop experiment prove?

- ☐ The electric charge is continuous
- ☐ It proves that electric charge is quantized
- ☐ The value of an elementary charge is $1.602.10^{-19} As$

Check



Millikan oil-drop experiment

PHYWE

Robert-Bosch-Breite 10
37079 Göttingen

Tel.: 0551 604 - 0
Fax: 0551 604 - 107

info@phywe.de
www.phywe.de

Slide	Score / Total
Slide 16: Oil drop experiment	0/1
Slide 17: Oil drop experiment 2	0/2

Total Score 0 / 3

Show solutions Retry

PHYWE
Robert-Bosch-Breite 10
37079 Göttingen
Tel.: 0551 604 - 0
Fax: 0551 604 - 107
info@phywe.de
www.phywe.de