MINSTRY OF EDUCATION AND SCIENC OF UKRAINE
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PHYSICS

LABORATORY OPERATIONS MANUAL EXPERIMENTAL VALIDATION OF ELECTRIC CHARGE DISCRETIZATION (MILLIKAN EXPERIMENT)

Dnepropetrovsk
2014

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LABORATORY OPERATIONS MANUAL “EXPERIMENTAL VALIDATION OF ELECTRIC CHARGE DISCRETIZATION (MILLIKAN EXPERIMENT)”

For the students of all specialties

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2014

Physics. Laboratory operations manual “Experimental validation of electric charge discretization (Millikan experiment)”. Materials of methodological support for subject of “Physics” for the students of all specialties / L.I. Bartashevskaia, A.S. Zaitsev, A.V. Chernai – D.: State Higher Educational Institution “National Mining University”, 2013.– 9 p.

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All authors took part in developing the model and methodological instructive regulations to the laboratory operations manual.

Approved by editorial board of SHEI”NMU” (Protocol No. 6 of 21.06.2014) ***по приказу методической комиссии направления подготовки 6.050301 Горное дело (протокол № от 2014 г.)***

The educational materials are developed for self-study of students of all engineering specialties to the laboratory work as well as control of practical and laboratory training on obligatory subject “Physics”.

Theory and devices, applied in the laboratory work, are considered.

The recommendations are focused on students’ training activation.

Releaser is professor I.P. Garkusha, Cand. Sc. {Physics and Mathematics}, Chairman of Department of Physics.

Laboratory research 3.33

EXPERIMENTAL VALIDATION OF ELECTRIC CHARGE DISCRETIZATION (MILLIKAN EXPERIMENT)

Devices and equipment: 1) personal computer; 2) computer model of Millikan experiment laboratory unit.

Objective: studying Millikan experiment; validating charge discreteness with the help of computer model of Millikan experiment laboratory unit.

Describing the device. Theory.

In 1908-1917 American researcher Millikan effected experimental validation of elementary charge value as well direct confirmation of electric charge discreetness.

As it is rather difficult to implement the experiment in the environment of university laboratory, computer model, proposed by the laboratory experiment is vey helpful. Fig. 1 demonstrates an experimental design involving horizontal capacity sheets (1); a vaporizer (2) to produce fine droplets; an electrical potential source (3), to charge the capacity producing voltage difference between the capacitor sheets; a button (4); X-ray generator (5); a microscope eyepiece (6), making it possible to see a motion of the fine droplets between two lines located at different levels; in the process, motion time is clocked with the help of timing device.

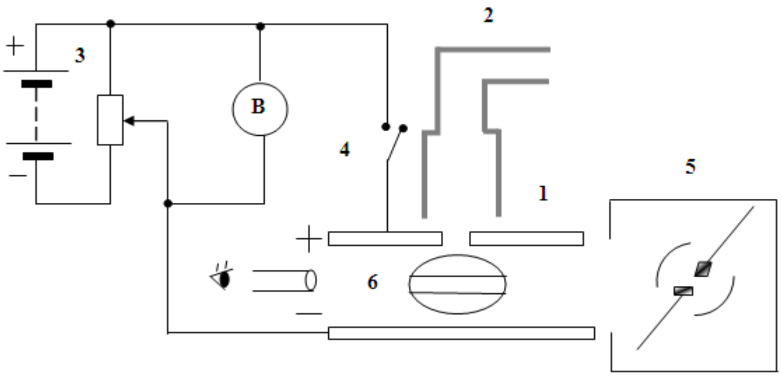
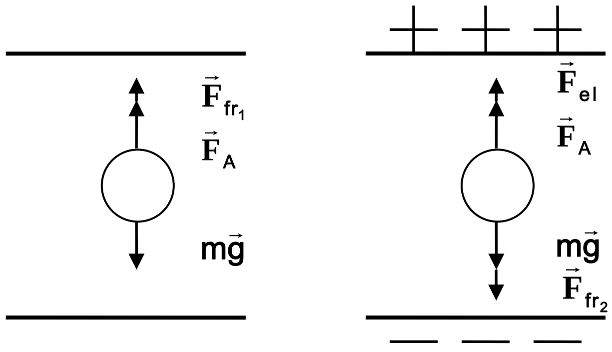


Fig. 1

The research considers motion of a droplet in hydrogen taking into account Archimedes force, and viscous force – Stokes force.

Fig. 2 demonstrates forces acting on a charged droplet without electric field (a) and in it (b). In the both cases, motion of the droplet is steady. If a) then the droplet moves down; if b) then it moves up.



a) b)

Fig. 2

Recording equations of the droplet motion in a vector form

$$\left.\begin{array}{l}\vec{F}_A + m\vec{g} + \vec{F}_{fr_1} = 0\\ \vec{F}_{el} + \vec{F}_A + m\vec{g} + \vec{F}_{fr2} = 0\end{array}\right\},$$

and in a scalar one

$$\left.\begin{array}{l}mg - F_{fr1} - F_A = 0\\ mg + F_{fr2} - F_A - F_{el} = 0\end{array}\right\}, \tag{2}$$

and taking into consideration the fact that Archimedean force is $F_A = \rho_{H_2} \cdot gV$, where ρ_{H_2} is hydrogen density, V is the droplet capacity, and at small velocities, the droplet velocity is proportional to its $F_{fr} = k\vartheta$ velocity, we obtain

$$\left.\begin{array}{l}mg - k\vartheta_0 - \rho_{H_2} gV = 0\\ mg + k\vartheta_1 - \rho_{H_2} gV - qE = 0.\end{array}\right\}$$

Expressing velocities of the droplet motion as ϑ_0 for case a) and ϑ_1 for case b), we obtain

$$\left.\begin{array}{l}\vartheta_0 == \dfrac{1}{k}(mg - \rho_{H_2} gV)\\ \vartheta_1 = \dfrac{1}{k}(\rho_{H_2} gV + gE - mg).\end{array}\right\}.$$

Dividing equation one by equation two, we obtain

$$\frac{\vartheta_0}{\vartheta_1} = \frac{mg \cdot \rho_{H_2} gV}{\rho_{H_2} gV + qE - mg} \tag{3}$$

In Millikan experiments, the majority of droplets getting into a gap between the sheets are charged negatively. Between the capacitor sheets, the droplets motion is almost uniform owing to the medium internal friction. A field, developed between the sheets, makes the droplet goes up; when it approaches upper sheet, breaking field makes it goes down under gravity.

Due to electric field switching on and off, the droplet may frequently repeat up/down motions between the sheets. Rapid change in the droplet velocity takes place at the moment of the field switching on and off; as (3) demonstrates such velocity changes are possible if only the droplet charge varies, when m, g, E, ρ_{H_2} , and V remain constant in this context.

Millikan supposes that a charged droplet, making its motion within a medium of gas ionized by X-ray, captures ions; that results in the droplet charge change, and, consequently, its velocity change. It should be noted, that for this work hydrogen is a medium; hence, the gas ionizing factors into origination of electrons and single-charged positive ions. As ion’s mass is much greater than that of electron, then its interaction cross-section with the droplet is several orders greatly that its interaction cross-section with electrons. That is why a droplet captures positive ion; hence, its negative charge decreases.

Initial charge of q_1 droplet, and its charge after $-q_2$ capture are proportional to ($\vartheta_0 + \vartheta_1$) and ($\vartheta_0 + \vartheta_2$) accordingly.

And ($q_2 - q_1$) difference is determined by the droplet charge.

$$\Delta q = q_2 - q_1 = \frac{g(m - \rho_{H_2} V)}{v_0 E} (\vartheta_2 - \vartheta_1) . \tag{3}$$

(Derivation of formula (3) is in Appendix).

In such a way, a value of a charged captured by the droplet, is proportional to the droplet motion differential velocity before capture and after it.

Numerous experiments by Milliken suggest that: wherever electric charge q occur – on insulators, conductors, or in metal – it is always a sum of some elementary charges to be invariable Δq=k**e**, where k=1; 2; 3…..

Order of measurements

1. Familiarize yourself with the device operational scheme.

2. Select any of droplets in free fall and fix it pushing space key when the droplet is crossing upper line. Connect X-ray source by means of **short-time** capturing F4.

3. When trace-controlled droplet reaches lower line, stop times using space key.

4. Using key “↑” switch electric field on and fix the moment when selected droplet cross upper line.

5. Using key “↓” switch electric field off, and change to a new experiment

6. Study automatically completed table containing values of charges “captured” by Δq droplet. Make sure, that each value of charge, obtained by the droplet, is divisible by a whole number of elementary charges **e**=$1.6 \cdot 10^{-19}$ Coulomb.

Revision

1. How can a droplet obtain initial charge?
2. What is the way for hydrogen ionizing in this experiment?
3. What is the condition for uniform motion of charged droplet in electric field?
4. What is the condition for uniform motion of uncharged droplet?
5. What is elementary charge? Which particles have it?

References

1. Сивухин Д.В. Общий курс физики/ Д.В. Сивухин. – М.: «Наука», 1997. – 688 с.

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Appendix 1

From the equation (3) we find a value of the droplet charge

$$q = \frac{(\vartheta_0 + \vartheta_1) g (m - \rho_{H_2} v)}{\vartheta_0 E}. \qquad (\Pi.1)$$

The droplet mass we express through its density ρ_M and volume $V = \frac{4}{3}\pi r^3$.

After substituting $m = \rho_M \cdot V = \rho_M \frac{4}{3}\pi r^3$ in (П.1), we obtain

$$q = \frac{(\vartheta_0 + \vartheta_1) g \cdot \frac{4}{3}\pi r^3 (\rho_M - \rho_{H_2})}{\vartheta_0 E}.$$

If electric fields are not available, the particle motion is described by the formula

$$m\vec{g} + \vec{F}_{fr} + \vec{F}_A = 0$$

In scalar form, the law may be expressed as

$$mg – F_A – F_{fr} = 0 \qquad (\Pi.2)$$

Allow for the fact that $F_{fr} = F_{Stocks} = 6\pi\eta r \upsilon_0$, where η is coefficient of internal friction of hydrogen; after substituting F_A and $F_{тр}$ in (П.2), we obtain

$$(\rho_M - \rho_{H_2}) \cdot \frac{4}{3}\pi r^3 g = 6\pi\eta r \vartheta_0. \qquad (\Pi.3)$$

Expressing from (П.3) $r = \sqrt{\frac{9\eta\vartheta_0}{2g(\rho_M - \rho_{H_2})}}$ and substituting it in (П.1), we obtain

$$q = \frac{\vartheta_0 + \vartheta_1}{E} \cdot \frac{18\pi\eta}{\sqrt{2g}} \cdot \sqrt{\frac{\eta\vartheta_0}{(\rho_M - \rho_{H_2})}}. \qquad (\Pi.4)$$

Neglecting ρ_{H_2} to compare with ρ_M, and substituting all known values, write (П.4) over as

$$q = \frac{12{,}77(\vartheta_0 + \vartheta_1)\eta}{E} \sqrt{\frac{\eta\vartheta_0}{\rho_M}},$$

And expression for Δq is:

$$\Delta q = \frac{12{,}77(\vartheta_2 - \vartheta_1)\eta}{E} \sqrt{\frac{\eta\vartheta_0}{\rho_M}}.$$

The formula coincides with that, demonstrated in a laboratory work, considering a model of Milliken experiment with PC; however, symbols of some values don’t coincide with universally accepted ones.

At this rate, viscosity η of medium, in which the droplet motion takes place, is specified by letter P, and oil density – by letter R.

Inclusive of that, expression for Δq takes the form

$$\Delta q = \frac{12{,}77(\vartheta_2 - \vartheta_1)\,P}{E}\sqrt{\frac{P\,\vartheta_0}{R}}\ .$$

The work calculates q and Δq automatically after each experiment; in this context, the results table is completed automatically too.

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