重庆大学-辛辛那提大学联合学院

学生实验报告

CQU-UC Joint Co-op Institute (JCI)
Student Experiment Report

实验课程名称 Experiment Course Name　大学物理实验（I）

开课实验室（学院）Laboratory (School)　JCI

学院 School　CQU-UC　年级专业班 Student Group　18ME01

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学年 Academic Year　2019　学期 Semester　Spring

成绩 Grade	
教师签名 Signature of Instructor	

批改说明 Marking instructions:

指导老师请用红色水笔批改，在扣分处标明所扣分数并给出相应理由，在封面的平时成绩处注明成绩。

Supervisors should mark the report with a **red ink pen**. Please write down **the points deducted** for each section when errors arise and specify the corresponding reasons. Please write down **the total grade** in the table on the cover page.

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实验时间 Date of Experiment______2019______年 Year______02______月 Month______25______日 Day

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实验目的 Description/Instruction:

The oil drop experiment was carried out by Robert Millikan and Harvey Fletcher. In this report, the purpose of the experiment is to measure the charge of a single electron. The main method is to balance gravity and electricity, so that oil droplets are suspended between two metal electrodes. According to the known electric field strength, the total charge of the whole oil drop is calculated. After repeated experiments on many oil droplets, we found that the total charge value of all oil droplets was a multiple of the same number, so we can identify this value as the charge e of a single electron. We also can Acquire the character and method of the experiment and understand the principle and application of CCD image sensor and learn the measurement method of TV microscope.

原理和设计 Principle and Design:

1. Dynamic measurement method：

Considering a small enough oil drop's movement, the radius of the oil drop is view as r and its mass is m1. Due to the air is viscous liquid, the oil drop will be influenced by the resistance caused by the air's viscous character. By the stokes' law, the resistance is proportional to the speed of the oil drop. Suppose the oil drop's speed is Vf and it is fixed, an equation could be figured out:

$$m_1 g - m_2 g = K v_f$$

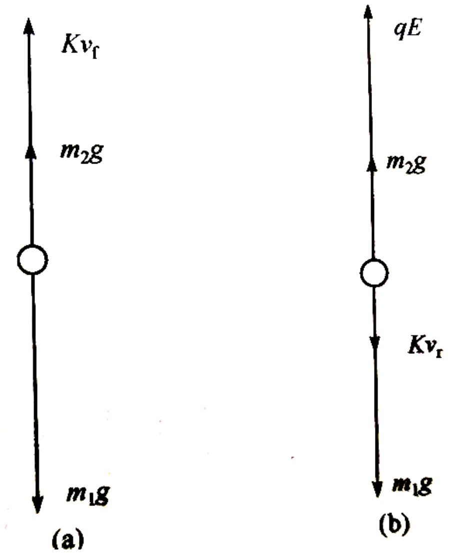
During the equation, m2 is the air's mass which volume equals the oil drop. K is the proportional constant and g is the acceleration of the gravity. The stress state is as follows in the figure's part a.

If the oil's charge is q and it is placed in an electric flied with a flied strength E. Suppose the electric force is qE and its direction is opposite to the gravity. Then, the oil drop will lift as the figure's part b. An equation could be figured out as follows:

$$qE = (m_1 - m_2)g + Kv_r$$

By killing the proportional constant K, an equation could be figured out:

$$q = \frac{(m_1 - m_2)g}{Ev_f}(v_f + v_r)$$



However, measure r and m1 is difficult. Therefore, m1 is wished to be substituted by the density of the air and the oil. Then, by the stokes law, the resistance of the air is proportional to the speed and the proportional constant is 6πηr. Then the equation for the Vf is as follows:

$$v_f = \frac{2gr^2}{9\eta}(\rho_1 - \rho_2)$$

Then, r could be calculated out and replace the r in the equation above.

$$q = 9\sqrt{2}\pi\left[\frac{\eta^3}{(\rho_1 - \rho_2)g}\right]^{\frac{1}{2}} \frac{1}{E}(1 + \frac{v_r}{v_f})v_f^{\frac{3}{2}}$$

At last, q could be figured out. However, when the diameter of the oil drop equals to the distance between the air molecules, the constant need to be fixed as follows:

$$\eta' = \frac{\eta}{1 + \frac{b}{\rho r}}$$

The p in the equation is the atmosphere's pressure and b is the fixing constant which equals 0.00823N/m. Therefore, Vf could be justified as follows:

$$v_f = \frac{2gr^2}{9\eta}(\rho_1 - \rho_2)(1 + \frac{b}{pr})$$

At last, by substituting E and viewing the accuracy is not so high, the equation of q could be substituted as follows:

$$q = 9\sqrt{2}\pi d\left[\frac{\eta^3}{(\rho_1-\rho_2)g}\right]^{\frac{1}{2}}\frac{1}{U}(1+\frac{v_r}{v_f})v_f^{\frac{3}{2}}(1+\frac{b}{pr})^{-\frac{3}{2}}$$

Because some numbers in the equation above do not change during the experiment process, they could be replaced by C:

$$q = C\frac{1}{U}(\frac{1}{t_f}+\frac{1}{t_r})(\frac{1}{t_f})^{\frac{1}{2}}(1+\frac{b}{pr})^{-\frac{3}{2}}$$

2. The equilibrium measurement method:

The thought of this method is that the oil drop will stay in a place in the filed or its speed is constant. When the oil drop stays stable in the electric filed, the force it received will turns to cancel each other.

$$qE = (m_1 - m_2)g$$

When the oil drop's speed is constant and it stays in the electric filed, the equation could be acquired as follows:

$$q = 9\sqrt{2}\pi d\left[\frac{(\eta s)^3}{(\rho_1-\rho_2)g}\right]^{\frac{1}{2}}\frac{1}{U}(\frac{1}{t_f})^{\frac{3}{2}}(1+\frac{b}{pr})^{-\frac{3}{2}}$$

At last, the elementary charge constant could be figured out by graphing.

The constant numbers need in the experiment is as follows:

$\rho = 981kg/m^3(293.15K)$	$b = 8.22\times10^{-3}(m\times Pa)$
$g = 9.79m/s^2$	$p = 1.013\times10^5 Pa$
$\eta = 1.83\times10^{-5}(Pa\times s)$	$d = 5.00\times10^{-3}m$

实验器材 List of instruments and materials:

【Millikan oil drop meter】

The experimental instrument consists of a host computer, a CCD imaging system, an oil drop box, a monitor, a sprayer and other components.

The host computer comprises a controllable high-voltage power supply, a timing device, ad sampling and visual processing multiple single infinite blocks, the CCD imaging system comprises a CCD sensor, optical imaging components and the like, and the oil-filled box comprises high-voltage electrodes, lighting devices, windproof policies and other components. The monitor is a video signal output device. the main unit is shown schematically in the figure below.

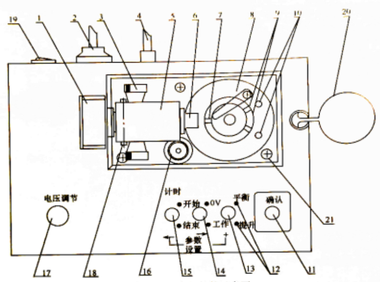


图 5.7.2 主机部件示意图

1. CCD 盒；2. 电源插座；3. 调焦旋钮；4. Q9 视频接口；5. 光学系统；6. 镜头；7. 观察孔；8. 上极板压簧；9. 进光孔；10. 光源；11. 确认键；12. 状态指示灯；13. 平衡/提升切换键；14. 0V/工作切换键；15. 计时开始/结束切换键；16. 水准泡；17. 电压调节旋钮；18. 紧定螺钉；19. 电源开关；20. 油滴管收纳盒安放环；21. 调平螺钉 (3 颗)

The CCD module and the optical imaging system are used to capture the image of oil droplets in the darkroom. at the same time, the image information is transmitted to the video processing module of the host computer. during the experiment, the object distance can be changed through the focusing knob, so that the image of oil droplets can be clearly displayed in the window of the CCD sensor.

The voltage adjusting knob can adjust the voltage between the polar plates to control the balance, falling and lifting of oil drops. The timer " start / end" button is used to time: the Ovi work button is used to switch the working state of the instrument: " balance”. The " lift" button can switch the oil drop balance or lift status; The " confirm" button can display the most measured data on the screen, thus eliminating the process of manually recording data after each measurement is completed and allowing the operator to focus more attention on the nature of the experiment.

The oil-filled box is a key component, and its specific composition is shown in the following figure.

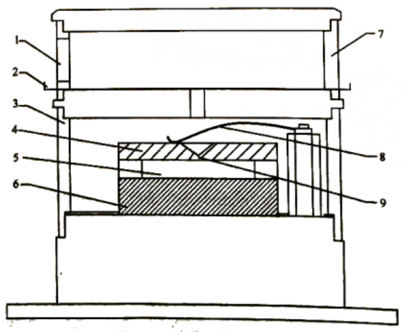


图 5.7.3 油滴盒装置示意图

1. 喷雾口；2. 进油量开关；3. 防风罩；4. 上极板；5. 油滴室；6. 下极板；7. 油雾杯；8. 上极板压簧；9. 落油孔

The upper and lower polar plates are supported by bakelite rings, and the contact surfaces between the three can be machined to control the non-parallelism and spacing error between the polar plates below 0.0 IMM. This structure basically eliminates the barrier effect and the " edge effect" between the polar plates, and better ensures that the oil drop chamber is in a uniform electric field, thus effectively reducing the experimental error.

The bakelite ring is provided with two light inlet holes and an observation hole, the light source provides illumination to the oil drop chamber through the light inlet holes, and the image illumination of the oil drop captured by the imaging system through the observation hole is provided by the high-brightness light emitting diode with light collection, and the service life of the imaging system is prolonged. The oil mist cup can temporarily store oil mist so that the oil mist does not escape prematurely. the oil amount can be controlled by using the oil amount switch. the wind shield can avoid the influence of outside air flow on oil droplets.

The equation of the principle is:

$$q = 9\sqrt{2}\pi d\left[\frac{(\eta s)^3}{(\rho_1 - \rho_2)g}\right]^{\frac{1}{2}}\frac{1}{U}\left(\frac{1}{t_f}\right)^{\frac{3}{2}}\left(1+\frac{b}{pr}\right)^{-\frac{3}{2}}$$

And the constant numbers in the equation are all showed above.

Note:

1. Because the density of the oil is much larger than the air’s, the density of the air could be ignored.
2. The standard pressure of the atmosphere is 101325Pa when the temperature is 293.15K and relative humidity is 50%. However, the pressure and the temperature could be measured by the device.
3. The relations between the temperature and the density of the oil is showed as follows:

W(K)	273.15	283.15	293.15	303.15	313.15
$\rho\ (kg/m^3)$	991	986	981	976	971

4. Generally, the viscosity of the liquid is not affected by the pressure so much. When the atmosphere is 5 times larger, the viscosity only increases 10%. Therefore, the effect of the pressure on the viscosity is ignored usually. The effect of the temperature on the viscosity could be represented as the Scotland equation:

$$\frac{\mu}{\mu_0} = \frac{(\frac{T}{T_0})^{\frac{3}{2}}(T_0 + T')}{(T_0 + T')}$$

The μ_0 in the equation is the absolute temperature's viscosity and it usually viewed as the value when T equals 273.15K, $1.71 \times 10^{-5} kg/(m \times s)$.

实验步骤 Implementation:

1. Read some relative books and get familiar with the method.
2. Adjust the instrument so that it is horizontal.
3. Practice controlling oil droplets (Take the equilibrium method as an example).

1）How to select the appropriate oil droplets.

The three parameter setting keys are respectively in the " end", " work" and " balance" States. the balance voltage is set to about 400 v to spray oil droplets. adjust the focus knob to make the screen display most of the oil droplets. visible charged oil droplets rapidly rise out of the field of view and uncharged oil droplets fall out of the field of view. after about 10 seconds, the oil droplets decrease. select the slowly rising oil droplets as the temporary target oil droplets and switch the " ov work" key. at this moment, the voltage between the polar plates is 0 v. among the temporary target oil droplets, select the oil droplets falling at a speed of 0.2 - 0.5 div / s as the final target oil droplets, and adjust the focus knob to minimize the oil droplets.

2）Confirmation of equilibrium voltage.

After the target oil drops are focused to the minimum and brightest, carefully adjust the " voltage regulation" during the balance so that the oil drops are balanced on a certain grid line, wait for a period of time (about 2 min), and observe whether the oil drops are drifting away from the grid line. if the oil drops are always drifting away in the same direction, then the balance voltage needs to be readjusted. If it is basically stable in the grid line or only performs slight Brownian motion below the grid line, then it can be considered that the oil droplets have reached a mechanical balance, and the voltage at this time is the equilibrium voltage.

3）Controlling the movement of oil droplets.

The oil drop is balanced on the first grid line at the top of the screen, the working state key is switched to "ov" and the green indicator light is lit. at this time, the upper and lower polar plates are grounded at the same time, the electric field force is zero, and the oil drop falls under the action of gravity, buoyancy and air resistance. the oil drop moves through a period of variable speed first, then changes to uniform speed, but the time of variable speed movement is very short (less than 0.01s, which is equivalent to the precision of the timer), so it can be considered that the oil drop falls at an instant uniform speed. when the oil drop falls on the grid line marked with 0, the timer starts to record the time of falling of the oil drop. When the oil drop falls to the grid line with the distance mark (1.6), press the timing key again, and the timer stops counting (the timing position is shown in figure 5.7.4). at this time, the oil drop stops falling. the " ov / work. do" key automatically switches to " work" and the " balance / lift" key is in " balance". this measurement data can be recorded on the screen by the " confirm" key to switch the " balance / lift" key to " lift". at this moment, the plate voltage increases about 200 v from the original balance voltage, and the oil drop immediately moves upward. when the oil drop rises to the top of the screen, switch to " balance" find a balance voltage. "

4. Measure the charge formally.

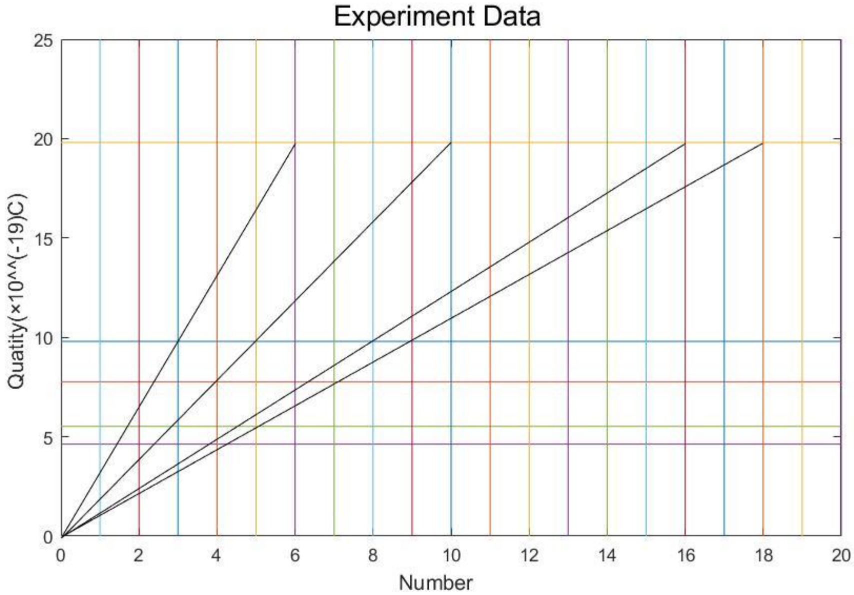
1) Open the power and start the instrument. Turn the instrument into the working state. Place the " balance / lift" key in " balance.
2) Adjust the balance voltage to 400 or so, and spray oil mist into the oil-filled gold through the spray port. at this time, a large number of moving oil droplets will appear on the monitor to select suitable oil droplets, and carefully adjust the balance voltage u to make it balance at the beginning (Top) Grid line.
3) Switch the " 0v / work" status key to " 0v" and the oil drops begin to fall. when the oil drops fall to the grid marked with " 0", press the timer start key immediately. at the same time, the timer starts to record the falling time of the oil drops.
4) When the oil drops fall to the grid marked with distance (e.g. 1.6), press the timer end key immediately. at the same time, the timer stops counting, and the oil drops immediately stop. the " 0v / work" key automatically switches to " work". the " balance voltage and uniform falling time" results measured this time are recorded on the monitor screen at the same time through the " confirm" key.
5) Place the " balance / lift" key in " lift" and the oil droplet will move upward. when returning to the grid line with the " 0" mark, switch the " balance / lift" key to the equilibrium state, and the oil droplet will stop rising and readjust the equilibrium voltage. (Note: If the equilibrium voltage here changes abruptly, the oil droplet will get or lose electrons. this measurement cannot be counted from step 2) Start searching for oil drops again.)
6) Repeat 3） to 5） and record the data (balance voltage v and falling time 1) on the screen. after five measurements are completed, press the " confirm" key. the system will calculate the average balance voltage and average and fast falling time of the five measurements, and automatically calculate and display the charge amount q of the oil drop based on these two parameters.
7) Repeat 2） to 6） to find all oil drops in total, and measure the charge quantity q of each oil drop.

实验结果和数据处理 Results and Data processing:

Result：

Experiment Data													
	Balance Voltage V（V）						Free falling Time t (s)						Q(*10^(-19)C)
	Trial1	Trial2	Trial3	Trial4	Trial5	UA	Trial1	Trial2	Trial3	Trial4	Trial5	UA	Q
Dro1	53	53	40	29	31	14.35	42	42.94	33.54	29.16	30.01	8.15	9.8
Dro2	49	111	2	16	66	53.59	32.31	66.01	22.84	26.01	39.09	21.43	7.766
Dro3	13	2	16	15	26	10.64	43.96	32.7	45.51	43.26	58.85	11.59	19.812
Dro4	87	84	117	82	2	53.39	41.1	39.65	52.57	38.49	24.71	12.32	4.626
Dro5	55	2	2	80	12	44.03	76.26	48.1	45.78	88.88	50.37	24.21	5.52

（Table 1）



（Graph1）

Data processing

According to Table1 and Graph1, we can briefly conclude that q=19.812*10^(-19)/10=1.98*10^(-19). After calculation, $error = \frac{1.98\times10^{-19}c-1.600\times10^{-19}c}{1.600\times10^{-19}c} = 23.75\%$, the error is 23.75%.

实验讨论 Discussions:

1. What are the main factors influencing the experimental results?
1) Modification of Air Viscosity Coefficient.
2) The lack of representation in oil droplet selection makes it difficult to calculate the minimum common denominator.
3) The subjective error of manual timing is large

2. What would happen if distilled water was used instead of clock oil?
1) Pure water is not charged, water droplets can not be balanced in the electric field, all without charge can be measured.
2) Water evaporates too fast, so the mass changes constantly, so the observation time will be very short. The use of oil droplets does not have this problem, the volatilization rate is very low.

3. How to judge the level of the two parallel plates in the oil drop box? What is the effect of low level on the experiment?
1) Judging principle:
   If the parallel plates are not horizontal, then the electric field force and gravity are not in a straight line, and the oil droplets drift to the left or right or back, or even move out of the field of view, so we can judge whether the oil droplets are stationary or uniform motion in parallel.
2) Phenomenon if not horizontal:
   Gravity has a component parallel to the direction of the plate. If not applied voltage, the oil droplet will have velocity in the parallel direction. If not horizontal, the acceleration component in the vertical direction of the plate will be balanced with electric field and air resistance, and the measured elementary charge is not accurate.