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 College Physics Experiment II

开课实验室（学院）Laboratory (School) CQU-UC

学院 School JCI 年级专业班 Student Group 2018 ME01

学生姓名 Student Name 易弘睿 学号 Student Number 20186103

学年 Academic Year 2019——2020 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.

重庆大学-辛辛那提大学联合学院________________________________实验报告

JCI ____ Experiment Report

学院 School Chongqing University 年级专业班 Student Group 2018ME01
姓名 Name 易弘睿 学号 Student Number 20186103
开课学院、实验室 Academic School/ Laboratory CQU-UC
实验时间 Date of Experiment 2020 年 Year 4 月 Month 16 日 Day
报告时间 Date of Report 2020 年 Year 4 月 Month 19 日 Day

课程名称 Course Name	College Physics Experiment II	实验项目名称 Experiment Project	Measurement of Plank Constant by Photoelectric Effect Method	实验项目类型 Type of experiment project				
				验证 Verification	演示 Presentation	综合 Comprehensive	设计 Design	其他 Others
指导老师 Supervisor	边立功	成绩 Grade		√				

实验目的 Description/Instruction:

1. Understand the basic law of photoelectric effect and deepen the understanding of the quantum nature of light
2. Verify Einstein equation and measure Plank constant.
3. Measure the photoelectric characteristic curve of the phototube, and verify that the saturated photocurrent is proportional to the intensity of the human jet.

原理和设计 Principle and Design:

When a certain frequency of light irradiates a metal surface, electrons escape from it. This phenomenon is called photoelectric effect. Einstein believes that light emitted from a point does not propagate energy to space in the form of continuous distribution as pointed out by Maxwell's electromagnetic theory, but radiates one by one in the form of HV as the unit of energy (photoquantum). According to this theory, in the photoelectric effect, when free electrons in metals absorb the hv energy of a photon from the human beam, if they do not lose energy due to collision on the way, part of them is used to escape work W, and the rest is the maximum kinetic energy of electrons after they escape from the metal surface。

$$\mathrm{m}v_{max}^2 = 2\mathrm{hv} - 2w_s \tag{1}$$

This is the famous Einstein equation. In the formula, h is Planck constant and the accepted value is：$6.6260755{\times}10^{-34} J\cdot S.$

That explain:

(1) The photon energy hv is less than w_s, which can not produce photoelectric effect.

(2) Only when the frequency of the incident light is greater than the threshold frequency equal to w_s ,can the photoelectric effect be produced. The higher the frequency of the incident light is, the greater the

initial kinetic energy of the escaped photoelectron will be.

(3) The intensity of light means the density of photon flow, that is, the intensity of light only affects the size of photocurrent formed by photoelectrons.

In this experiment, deceleration field method is used. As shown in *Figure 1*, the light with V and P intensity is irradiated on the cathode K of the photocell, and the photoelectrons emitted from K move towards the anode A, forming a photocurrent in the outer circuit. With a reverse voltage added between the cathode and the anode, a repulsive electric field is established between the electrodes K and A to prevent the electrons from moving towards the anode. With the increase of voltage, the photoelectrons reaching the anode will move. It decreases gradually until the photoelectrons with the maximum kinetic energy are blocked and the optical current in the outer circuit is zero. The voltage value at this time is called cut-off voltage U, that is, cut-off voltage U.

$$2eU_s = mV_{max}^2 \tag{2}$$

Take it to the equation:

$$eU_s = hv - w_s \tag{3}$$

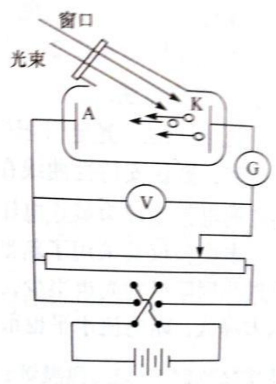

Figure 1 The Structural Diagram of the Experimental Device

For the same photocathode, the cut-off frequency U has a linear relationship with the frequency v of the incident light, and the slope k of the straight line is h/e. It can be seen that the Planck constant h can be obtained by measuring the cut-off frequency U and making the U-v curve for different frequencies of light. Where the electronic charge e $= 1.6 \times 10^{-19}$C

Figure 2 shows the curve of the photocurrent varying with the voltage. There are some unfavorable factors in the actual measurement of theoretical values that will affect the measurement results. A little negligence will bring about great errors for the following reasons:

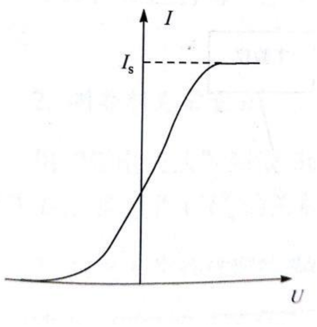

Figure 2 The Photocurrent over the voltage

(1) Dark current is a linear relationship between dark current and applied voltage caused by hot electron

emission and tube charging and leakage when photovoltaic tube is not illuminated by light.

(2) Anode emission current photocell is made of platinum, tungsten and other materials with high escape potential. Because cathode materials are deposited in use, photoelectrons will be emitted when exposed to visible light. The rejection electric field of cathode emission will result in reverse saturated current for the anode emission. Although the instrument avoids direct beam irradiation of the anode, the light scattered from the cathode is inevitable.

(3) The cathode of photocell is made of alkali metal material with low escape potential. This material also has oxidation tendency in high vacuum, so the escape potential of the cathode surface is different. With the increase of reverse voltage, the photocurrent does not cut off abruptly, but tends to reach zero gently after a faster decrease, so it needs a galvanometer with very high sensitivity to detect.

The I-U curve of the phototube is shown in *Figure 3*. The current value of each point on the measured curve actually includes the above two currents and the forward current generated by the bright electro-optic effect. Therefore, the volt-ampere curve is not tangent to the U-axis because the value of dark current is very small compared with the cathode forward current. Therefore, the influence of dark current on the cut-off voltage and the anode emission current can be neglected. To determine the cut-off voltage, the following two methods can be used:

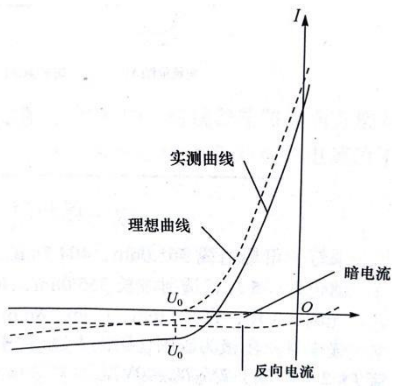

Figure 3 Different Current Values over Voltage

(1) Zero current method. Phototube anode is made of material with larger work escaping, and evaporation of cathode material is prevented as far as possible during the fabrication process. The anode of phototube is electrified before the experiment, and the cathode material sputtered on it is reduced. In the experiment, the incident light is avoided to be directly irradiated on the anode, which can greatly reduce its reverse current. Its safety characteristic curve is very close to that of Fig 1. Therefore, the measured curve is close to that of U. The potential difference at the intersection of axes is approximately equal to the cut-off voltage U. This is the intersection method.

(2) Although the photocurrent emitted by the anode of the inflection point method is large, in the structure design, if the anode current can be saturated quickly, the volt-ampere characteristic curve has an obvious inflection point after the cathode current enters the saturation section as shown in *Figure 3*. The potential difference of the inflection point is the cut-off voltage U.

A new type of photoelectric tube is used in this experimental instrument. Its special structure prevents light from directly irradiating the anode, and the light reflected from the cathode to the anode is very few. With the new material and manufacturing technology of cathode and anode, the reverse current of the anode is greatly reduced and the level of dark current is also very low. Therefore, zero current method is recommended to measure the cut-off voltage.

实验器材 List of instruments and materials:

1. ZKY-GD-3 photoelectric effect experimental instrument. The instrument consists of mercury lamp and power supply, color filter, diaphragm, photoelectric tube, tester (including photoelectric tube power supply and micro-current amplifier).
Mercury lamp: available spectral lines 365.0, 404.7, 435.8, 546.1, 577.0 and 579.0 nm.
2. Filter: 5 pieces, transmission wavelength 365.0 nm, 404.7 nm, 435.8 nm, 546.1 nm, 577.0 nm.
3. Aperture: 3 pieces, diameter 2mm, 4mm, 8mm.
4. Phototube: anode nickel ring, bright silver-oxygen-potassium (Ag-O-K), spectral response range 320~700 nm, dark current $1 < 2\times10^{-13}$A ($-2V < U_{AK} < 0V$).
5. Phototube power supply: 2 gears (-2~0V and -2~+30V), three-half display, stability less than 0.1%.
6. Microcurrent amplifier: 6-stop, 10^{-13}-10^{-8}A. Resolution 10^{-13}A. Three-half digit display, stability less than 0.2%.

实验步骤 Implementation:

1. Pre-test preparation

Connect the tester and mercury lamp power supply, preheat for 20 minutes；

Put the cover of mercury lamp and photocell dark box, align the light output port of mercury lamp dark box to the light input port of photocell dark box, adjust the distance between photocell and mercury lamp to about 40 cm and keep the same.

A special connection line is used to connect the voltage input terminal of the dark box of the phototube with the voltage output terminal of the tester (on the back panel) (red-red, blue-blue).

Zero adjustment: the "current range" selector switch is placed in the selected gear. After fully preheating, the instrument is zeroed before testing and zeroing. The "zero / measurement" switch is switched to "zero adjustment" gear and the "current zero adjustment" knob is rotated to make the current indication "000". After adjustment, the zero/measurement switch is switched to the test gear, and the experiment can be carried out.

Note: Before conducting each group of experiments, we must adjust the zero according to the above method, otherwise it will affect the accuracy of the experiment.

2. Measuring Planck constant h

The cut-off voltage U_0 under 365, 405, 436, 546 and 577 nm monochrome light was measured by zero current method. The Planck constant h was calculated from its slope by making V-U_S curve. Compared with the accepted values.

3. Measuring the Volt-ampere Characteristic Curve of Phototube

Put the voltage selection in - 2 ~+30V gear according to the key, select the appropriate "current range" gear (10-11A gear is recommended), and adjust the instrument to zero according to the previous method. A 2 mm diameter aperture and a 435.8 nm color filter are mounted on the light input port of the dark box of the photoelectric tube. The voltage corresponding to the current from zero to non-zero is recorded as the first set of data. After that, a set of data is recorded for each change of the voltage, and the voltage-ampere I-U characteristic curve of the photoelectric tube is measured.

4. Verify that the saturated photocurrent of the photocell is proportional to the incident light intensity

(1) The light intensity on the photocell is proportional to the area of the aperture.

When U_{AK} is 30V, the "current range" selection switch is placed in 10-10A block, and the instrument is zeroed according to the previous method. At the same spectral line and the same incident distance, the current values corresponding to the recording diaphragms of 2mm, 4mm and 8mm are in the table.

(2) The light intensity on the phototube is proportional to 1/d2 (d is the distance between the light source

and the phototube).
When UAK is 30V, the current range selector switch is placed in 10-10A block and zeroed. Under the same spectral line and diaphragm, the current corresponding to the different distances between the phototube and the incident light (such as 300mm, 400mm, etc.) is measured and recorded in the meter. It is also verified that the current is proportional to the incident light intensity.
Notes: In the use of the instrument, mercury lamp should not directly irradiate the photocell, nor should it continuously irradiate the photocell with diaphragm and filter for a long time, which will reduce the service life of the photocell. After the experiment is completed, please store the phototube with the phototube dark box to cover the incident light port of the phototube dark box.

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

1. Measure Plank constant h
Diaphragm hole: 4mm　　Current shield: 10^{-13}A　　Voltage range: -2~0V

Table 1: Stopping Voltages in Different Wavelengths

Wavelength λ (nm)	404.7	435.8	546.1	577.0
Frequency ν ($\times 10^{14}$Hz)	7.408	6.879	5.490	5.196
Stopping Voltage U_s (V)	-1.19	-0.9	-0.32	-0.2

$$U_S = \frac{h\nu}{e} - \frac{W_s}{e} \Rightarrow k = \frac{h}{e}$$
$$\Rightarrow h = ke = 0.4096 \times 10^{-19} \times 1.602 \times 10^{-14} = 6.562 \times 10^{-34} J \cdot s$$

Therefore, error can be calculated:

$$error = \frac{6.626 - 6.562}{6.626} \times 100\% = 1.00\%$$

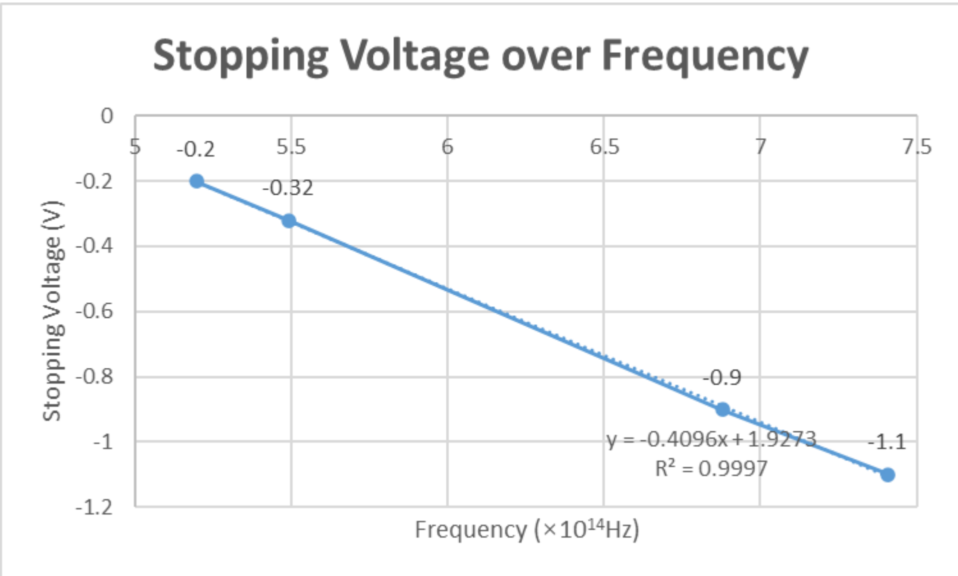

Figure 4 Stopping Voltage over Frequency

2. Measure the voltage-ampere characteristic curve of phototube
Diaphragm hole: 2mm　　Current shield: 10^{-11}A
Voltage range: -2~+30　　Wavelength: 577.0nm

Table 2 Currents in Different Voltages

U(V)	-1	-0.8	-0.6	-0.4	-0.3	-0.2	-0.1

I(A)	-0.04	-0.04	-0.04	-0.03	-0.02	0	0.03
U(V)	0	0.2	0.4	0.6	0.8	1	1.2
I(A)	0.07	0.24	0.59	0.9	1.09	1.19	1.27
U(V)	1.4	1.6	1.8	2	2.1	2.2	2.3
I(A)	1.33	1.37	1.39	1.41	1.42	1.42	1.43
U(V)	2.4	2.5	2.6	2.7	2.8	2.9	3
I(A)	1.43	1.44	1.44	1.46	1.46	1.47	1.47

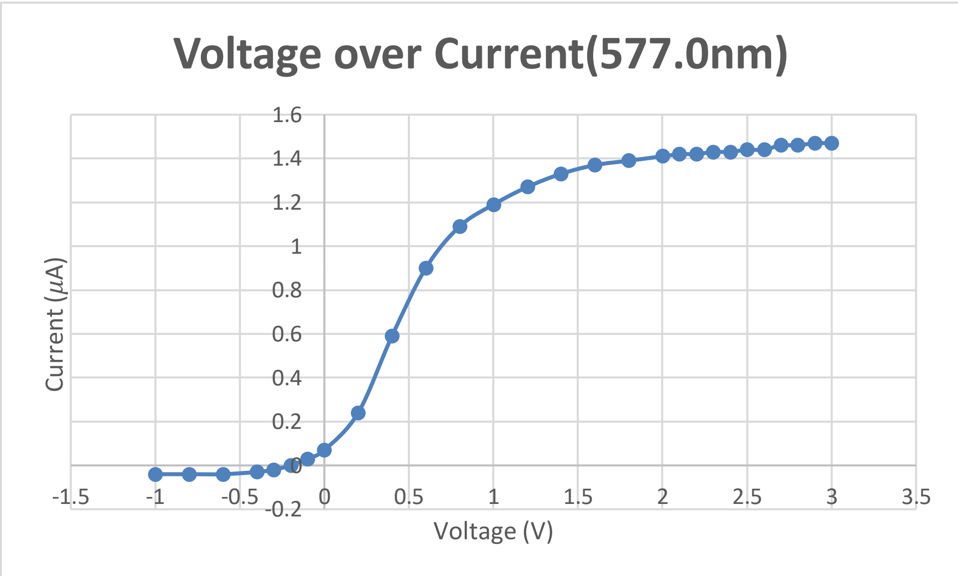

Figure 5 Voltage over Current

3. Verify that the saturated photocurrent of the photocell is proportional to the incident light intensity
Wavelength: 435.8nm Current shield: 10^{-13}A Voltage range: -2~0V

Table 3 Saturated Photocurrent in Different Diaphragm Holes

Diaphragm hole (mm)	ϕ2	ϕ4	ϕ8
Saturated photocurrent I_m (A)	7.0	27.4	99.5
Saturation voltage (V)	30		

实验讨论 Discussions:

1. Errors

Errors may come from two parts: measurement errors and instruments errors.

① For experiment 2, one of their error is 5%, which is a little large. The main reason of it is the number of experiments is too few, just 3 sets of data to form a straight line is too easy to lead accidental results. If we repeat the experiments for more times, it will be much better.

② For experiment 3, we can see that there is no data before U=0, which can not show -Us. It may caused by the range of instrument is not small enough to measure it. But when I choose a smaller range to measure the current, it will out of the range after about 15V. So expanding the range is also not feasible. Hence, the lack of data is coming from instrument rather than experimenter.

③ Other errors may come from instruments, such as aging and abrasion.

2. Discussion

(1) Does the photocurrent change with the intensity of the light source? Does the cutoff voltage change due to different light intensities?

Answer: Once reach the limit frequency, the greater the intensity of the light source, the higher the energy, and the more electrons that can be produced, so the current will vary with the intensity of the light source. The cut-off potential does not change due to the intensity of the light source, but it changes due to the different frequencies of the light. For the same metal, the higher the frequency of the light, the higher the cut-off potential.

(2) Theoretically, v-U, the intercept of the line is the escape potential ϕ (Ws/e) of the cathode material. In fact, there is a contact potential difference between the cathode and the anode, so the intercept of the measured curve is not equal to ϕ. Try to explain how the contact potential difference is generated, and it has no effect on this experiment.

Aswer: After the contact of the two metals, the metal with a smaller work function increases the potential due to the loss of electrons, and the metal with a larger work function lowers the potential due to the increase of electrons, and a potential difference forms between the two. Therefore, this potential difference affects the accuracy of the experiment.

物理实验 原始实验数据记录

Experiment Data

姓名 Name_____易弘睿_____学号 Student Number______20186103______实验时间 2020.4.9

实验名称 Name of experiment: Measurement of Plank Constant by Photoelectric Effect Method

仪器名称	量程	最小量	估读误差	仪器误差	零位误差
Digital Ammeter（10^-11/-12/-13A）	0~999	1	1		
Digital Voltage(V)	-2~0	0.001	0.001	0.001	
	-2~30	0.1	0.1	0.1	

实验数据 Experiment Data （表格自拟）

577.0nm

光电流与对应电压值(电流、电压数据表)

测量次数	1	2	3	4	5	6	7	8	
电压(V)	-1	-0.8	-0.6	-0.4	-0.3	-0.2	-0.1	0	(
电流(μA)	-0.04	-0.04	-0.04	-0.03	-0.02	0	0.03	0.07	0

增加列 减少列

遏止电压(单位: V) -0.2

546.1nm

光电流与对应电压值(电流、电压数据表)

测量次数	1	2	3	4	5	6	7	8
电压(V)								
电流(μA)								

增加列 减少列

遏止电压(单位: V) -0.32

435.8nm

光电流与对应电压值(电流、电压数据表)

测量次数	1	2	3	4	5	6	7	8
电压(V)								
电流(μA)								

增加列 减少列

遏止电压(单位: V) -0.9

404.7nm

光电流与对应电压值(电流、电压数据表)

测量次数	1	2	3	4	5	6	7	8
电压(V)								
电流(μA)								

增加列 减少列

遏止电压(单位: V) -1.19

普朗克常量

普朗克常量(单位：E-34 J·S) 6.55

关闭

100%透光率

光电流与对应电压值(电流、电压数据表)

测量次数	1	2	3	4	5	6	7	8	
电压(V)	-0.4	-0.2	0	0.2	0.4	0.6	0.8	1	1
电流(μA)	-0.03	0	0.08	0.23	0.59	0.9	1.09	1.19	1.

增加列 减少列

饱和电流值(单位:μA) 1.41

25%透光率

光电流与对应电压值(电流、电压数据表)

测量次数	1	2	3	4	5	6	7	8
电压(V)	0	0.5	1	1.5	2	2.5	3	
电流(μA)	0.02	0.2	0.28	0.34	0.36	0.37	0.37	

增加列 减少列

饱和电流值(单位:μA) 0.37

50%透光率

光电流与对应电压值(电流、电压数据表)

测量次数	1	2	3	4	5	6	7	8
电压(V)	0	0.5	1	1.5	2	2.5	3	
电流(μA)	0.04	0.37	0.59	0.67	0.72	0.75	0.75	

增加列 减少列

饱和电流值(单位:μA) 0.75

10%透光率

光电流与对应电压值(电流、电压数据表)

测量次数	1	2	3	4	5	6	7	8
电压(V)	0	0.5	1	1.5	2	2.5		
电流(μA)	0.01	0.07	0.12	0.13	0.15	0.15		

增加列 减少列

饱和电流值(单位:μA) 0.15

指导教师：边立功