Expt. 23 Photoelectric effect and measurement of Planck constant

Ⅰ. Purpose

(1) By using the photoelectric effect study the quantum nature of light.

(2) To verify the Einstein equation and determine the Planck constant.

(3) To obtain the voltage-current characteristics of a photoelectric tube.

Ⅱ. Apparatus

Mercury light and power supply, a range of light filters, diaphragm, photoelectric tube, bench, the Planck constant measuring instrument, connecting leads.

Ⅲ. Principle

When light with certain frequencies illuminates a metal electrons are emitted from the surface of that metal. This phenomenon is known as photoelectric effect. The kinetic energy of the emitted electrons does not depend on the intensity of light but does depend on the frequency of the incident light. This relationship can be written as: $h\nu = E_{\text{kinetic}} + W$, which is called the Einstein equation for the photoelectric effect.

In the Einstein equation, "h", the Planck constant is a very important physical quantity. In history, people have used many methods for its determination. Here, we will indirectly determine "h" through the photoelectric effect.

As shown in Figure 23 – 1, A is the anode of the photoelectric tube, C is the cathode. G is a galvanometer, V is a digital voltmeter, R is a rheostat. By adjusting R, the voltage U between A and C can be changed continuously from negative to positive. If we measure the photoelectric currents at different voltages, then we can draw the voltage-current characteristics of the tube (see Figure 23 – 2).

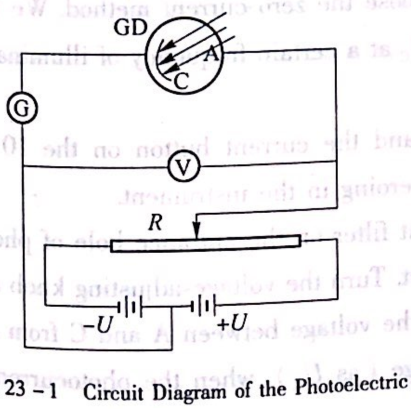

Figure 23 – 1 Circuit Diagram of the Photoelectric Effect Apparatus

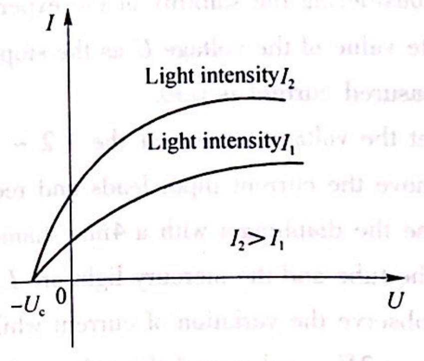

Figure 23 – 2 V – A Characteristics of the Photoelectric Tube

According to the conservation of energy, we have

$$h\nu = \frac{1}{2}mv_{max}^2 + h\nu_c \tag{23-1}$$

This formula shows the basic physics of the photoelectric effect. In the Einstein equation, $h\nu$ is the energy of incident photon, m is the mass of the electron, v_{max} is the maximum velocity of the emitted electron, ν_c is the threshold frequency of the photoelectric effect, and $h\nu_c$ is the work function of the metal. The threshold frequency varies from metal to metal. If we apply an increasing reverse voltage on electrode A (anode) until the emitted electrons which have maximum kinetic energy are prevented from reaching the anode then: $eU_c = E_k = \frac{1}{2}mv_{max}^2$, where U_C is called the stopping voltage.

Therefore
$$U_C = h(\nu - \nu_c)/e \tag{23-2}$$

If we measure values of U_C for various situations experimentally then h can be determined.

Ⅳ. Experimental

The photoelectric effect apparatus is shown in Figure 23 – 3.

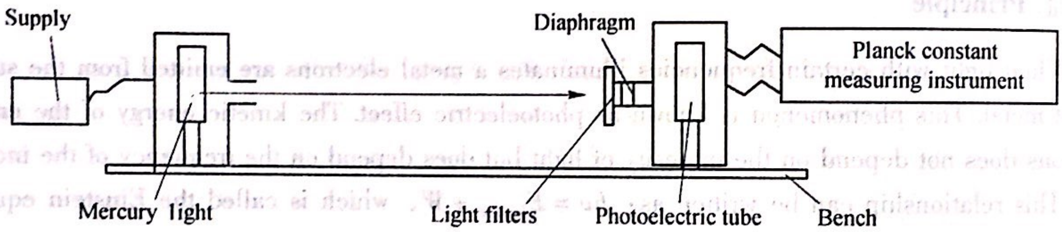

Figure 23 – 3 Photoelectric Effect Apparatus

1. Preparing

Turn on the supply, and allow it to warm up for 20 minutes. Cover the light sources with the hood. Adjust the distance between the photoelectric tube and the mercury light to about 40cm. Connect the voltage input terminals by connecting leads of the same colour.

2. Measurement of Planck constant (tube A)

Considering the stability of the experiment, we choose the zero-current method. We record the absolute value of the voltage U as the stopping voltage U_C at a certain frequency of illumination when the measured current is zero.

Set the voltage button on the $-2 \sim +2$V level, and the current button on the 10^{-12} A level. Remove the current input leads and reconnect after zeroing in the instrument.

Use the diaphragm with a 4mm diameter and a light filter on the entrance hole of photoelectric tube. The tube and the mercury light are $L = 400$mm apart. Turn the voltage-adjusting knob anticlockwise; observe the variation of current while decreasing the voltage between A and C from a positive value to -2V, and record the values of stopping voltage (as U_C) when the photocurrent reaches zero.

Measure and construct $U-V$ curve. Compare the calculated h value with the accepted value of the Planck constant h_0.

Work out the relative error $E = (h - h_0) / h_0$, where $h_0 = 6.626 \times 10^{-34}$ J · s. So far, we have measured the Planck constant h.

3. Measuring the $U-I$ characteristic curve of the photoelectric tube (tube B)

Turn on the supply; set the voltage on the $-2 \sim +30$V level and the current range on the 10^{-9}A level. Use the diaphragm with a 4mm diameter and a light filter on the entrance hole of photoelectric tube. The tube and mercury light are $L = 400$mm apart. Do the same zeroing as mentioned in procedure 2. Measure the required data and fill in the following table; construct the $U-I$ curve.

4. Verifying the relationship of the saturation current and the intensity of the incident light

Set $U = 30$V. Do the same as described in procedure 2. Measure the required data and construct the $I-P$ curves.

Notes: You must cover the output hole of the light source with the hood while changing the light filter. After you finish the entire experiment, please cover the input hole of the photoelectric tube. This avoids high intensity light illuminating the cathode and shortening the lifetime of the tube.

V. Questions

1. How did you determine the stopping voltage? Explain your method.
2. Can the light filter be inserted into the entrance of the diaphragm while doing the experiment? Explain your answer.

实验二十三　光电效应和普朗克常数测定

一、实验目的

（1）通过光电效应了解光的量子性。

（2）验证爱因斯坦方程，测定普朗克常数。

（3）测定光电管的伏安特性曲线。

二、实验仪器

汞灯及汞灯电源，各种滤色片，光阑，光电管，导轨，普朗克常数测量仪，电缆。

三、实验仪器原理

一定频率的光，照射到某一金属表面时，会有电子从金属表面逸出，这种现象叫做光电效应。逸出的电子动能与光的强度无关，只和入射光的频率有关。把它写成公式即为：$h\nu = E_{动能} + W$，这就是著名的爱因斯坦光电效应方程式。

爱因斯坦公式中的“h”是非常重要的物理量。历史上人们使用了各种方法来测量“h”值的大小。这里我们通过光电效应实验来间接地求出“h”值。

图 23－1 中 A 为光电管阳极，C 为光电管阴极，G 为微电流计，V 为数字电压表，R 为滑线电阻器。调节 R 可使光电管 A、C 之间的电压 U 从负电压到正电压连续变化。测得各电压下对应的光电流 I 的大小，就可得到光电管的伏安特性曲线（见图 23－2）。

根据能量守恒公式：

$$h\nu = \frac{1}{2}mv_{\max}^2 + h\nu_c \tag{23-1}$$

式（23－1）描述了光电效应的基本物理过程，爱因斯坦光电效应公式中 $h\nu$ 为入射光子的能量，m 为光电子的质量，$v_{\max}$ 为光电子的最大速度，ν_c 为光电效应的红限，$h\nu_c$ 为逸出功。不同金属有不同的红限。当金属 C（阴极）对面的电极 A（阳极）上的负向电压加大到具有最大动能的逸出电子也不能到达阳极 A 时，这个电压 U_C 就称为截止电压 U_C。即：$eU_C = E_{动能} = \frac{1}{2}mv_{\max}^2$，则有

$$U_C = h(\nu - \nu_c)/e \tag{23-2}$$

用实验方法测出不同情况下的 U_C 值，即可确定 h。

四、实验步骤及数据处理

光电效应的实验装置如图 23－3 所示。

1. 实验前准备

打开电源，预热20min，盖上光源遮光盖，调整光电管与汞灯距离约为40cm。将光电管电压输入端同色相连。

2. 普朗克常数 h 的测定（A管）

考虑到实验的稳定性我们采用了“零电流法”，可直接将某一频率下的光照射测得的电流为“0”时所对应的电压绝对值 U 作为该频率的截止电压 U_C。

将“测定仪”上的电压选择 $-2\sim+2$V 挡，电流选择 10^{-12}A 挡，测定仪电流输入电缆断开，调零后重新接上。

用直径4mm的光阑及滤色片装在光电管入光孔上，光电管与汞灯距离 $L=400$mm，然后逆时针方向调节“电压调节”旋钮，使A－C间的电压由+2V逐渐减小到－2V，同时观察光电流的变化，并记录光电流减少到零时刻对应的截止电压值（记为 U_C）。

用直线法拟合，并画出 $U-V$ 关系曲线。然后与公认值 h_0 比较，计算出实验的相对误差 $E=(h-h_0)/e$。式中 $e=1.602\times10^{-19}$C；$h_0=6.626\times10^{-34}$J·s。即可得出普朗克常数 h。

3. 测量光电管的伏安特性曲线（B管）

接通光电管电源，将电压选择 $-2\sim+30$V 挡，电流量程选择 10^{-9}A 挡。用直径为4mm的光阑，调节光电管与光源的中心距离 L 为400mm，实验开始前调零步骤同步骤2。

4. 验证光电管的饱和电流与入射光强的关系

取 $U=30$V，按以上步骤观测不同光阑孔径下饱和电流与光强间的关系和观测不同距离下饱和电流与光强间的 $I\sim P$ 关系。

注意：

每次更换滤色片时，必须先将光源的出光孔遮盖住。做完全部实验后，再用遮光罩将光电管入光孔盖住，避免强光直接照射阴极而缩短光电管寿命。

五、思考题

1. 实验用什么方法确定截止电压的？为什么要采用此种方法？
2. 实验时能否将干涉滤光片插到光源的光阑口上？为什么？

实验十九　光电效应和普朗克常数测定

1. 普朗克常数 h 的测定(A 管)

照射光波长λ/nm	365.0	404.7	435.8	546.1	577.0
频率 $V/\times10^{14}$Hz	8.214	7.408	6.879	5.490	5.196
截止电压 U_0/V					
普朗克常数 h					

用直线法拟合，并画出 U—V 关系曲线。然后与公认值 h_0 比较，计算出实验的相对误差 $E=(h-h_0)/e$。式中 $e=1.602\times10^{-19}C$；$h_0=6.626\times10^{-34}$J·S。即可得出普朗克常数 h。

2. 测量光电管的伏安特性曲线

滤波片 435.8nm	U_{AC}/V	−0.5	0.0	0.5	1.0	2.0	3.0	4.0	5.0	7.0	9.0
	$I/\times10^{-9}$A										
滤波片 365.0nm	U_{AC}/V	−0.5	0.0	0.5	1.0	2.0	3.0	4.0	5.0	7.0	9.0
	$I/\times10^{-9}$A										

3. 验证光电管的饱和电流与入射光强的关系

435.8mm	光阑孔径 ϕ	2	4	6	8
	$I/\times10^{-10}$A				
365.0nm	光阑孔径 ϕ				
	$I/\times10^{-10}$A				

435.8mm	光阑孔径 ϕ	2	4	6	8
	$I/\times10^{-10}$A				
365.0nm	光阑孔径 ϕ				
	$I/\times10^{-10}$A				

思考题