Experiment No. 5

Determination of Planck's Constant

I. OBJECTIVES

- To confirm the quantum theory of light, that photoelectrons depends only on the frequency of the incident light and is independent of the intensity, and calculate the Planck's constant h

II. BACKGROUND

The photoelectric effect experiment was able to show that electrons may be knocked out from a metal surface due to irradiation with light. Classical wave model of light predicted that the energy of these photoelectrons would depend on light intensity. In other words, the brighter the light, the greater energy. But according to the quantum theory of light, the energy of the photoelectrons depends only on the frequency of the incident light but is independent of the intensity. This situation may be clarified if light is considered as a stream of "photons" and it is assumed that each photoelectron is released by an individual photon possessing the energy $h\nu$, where h is the Planck's constant and ν is the frequency of the photon. Any excess energy of the impinging photons may be imparted to the electrons as kinetic energy upon leaving the surface, and the maximum kinetic energy a photoelectron can have follows from Einstein's Photoelectric Equation:

$$\boldsymbol{KE_{max} = h\nu - \phi} \qquad (1)$$

where ϕ is the work function of the metal, the minimum energy required by an electron to escape from the metal surface.

Figure 28 illustrates the set-up for the observation of the photoelectric effect. As can be seen in the figure, light of varying wavelength is shone on a clean metal plate inside an evacuated tube. If the frequency of the incident light is high enough, photoelectrons are emitted from the surface of the metal plate and propagate across a short gap to the collector plate. As the electrons travel through the tube, they are retarded by a reverse potential. When V is increased further, less electrons reach the cathode of the tube until a stopping potential V_0 is reached and no more electrons reach the collecting cathode and the ammeter registers a zero reading. The maximum kinetic energy KE_{max} of the photoelectrons is just then equal to eV_0 and equation (1) can be written as

$$\boldsymbol{h\nu = \phi + eV_0} \qquad (2)$$

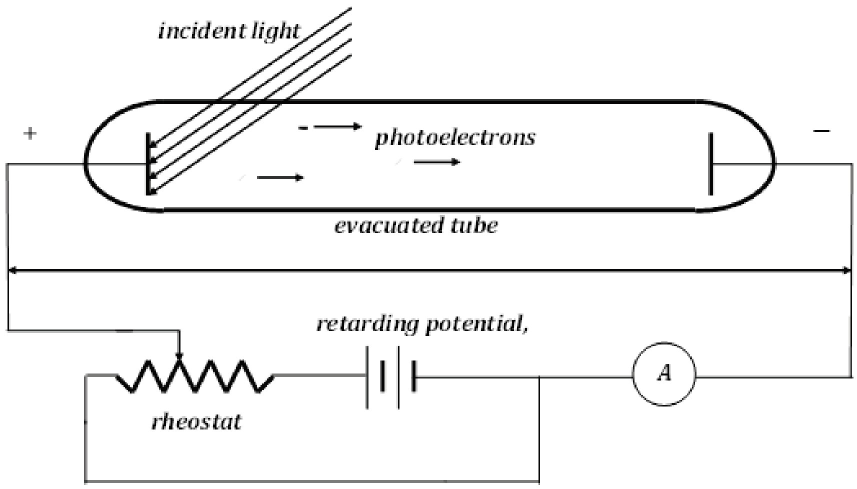

Figure 28. Experimental set up to study photoelectric effect

If the frequency of the incident light is increased by $\Delta\nu$, the electron energy increases by $h\Delta\nu$, so that the stopping potential is increased by ΔV_0 in order to bring the photoelectric current back to zero. An equation similar to equation (2) may also be applied:

$$\boldsymbol{h\Delta\nu = e\Delta V_0} \qquad (3)$$

i.e., the energy increase $h\Delta\nu$ is just compensated by the energy loss $e\Delta V_0$.

Therefore, if the stopping potential V_0 is plotted against ν, a straight line is obtained whose slope is just equal to the $\boldsymbol{h/e}$ ratio:

$$\boldsymbol{\frac{\Delta V_0}{\Delta\nu} = \frac{h}{e}} \qquad (4)$$

and whose y-intercept is equal to ϕ/e (as can be seen from equation (2)).

III. PROCEDURES

<u>Determining the Dependence of the Energy of Photoelectrons on the Intensity of Light</u>

1. With the equipment (shown in Figure 29) already set up, focus the light from the mercury vapor light source onto the slot in the white reflective mask on the h/e apparatus. *(The white reflective mask in the h/e apparatus is made of a special fluorescent material. This allows you to see the ultaviolet line as a blue line, and it*

also makes the violet line appear as more blue. You can see the actual colors of the light if you hold a piece of white non-fluorescent material in front of the mask.)

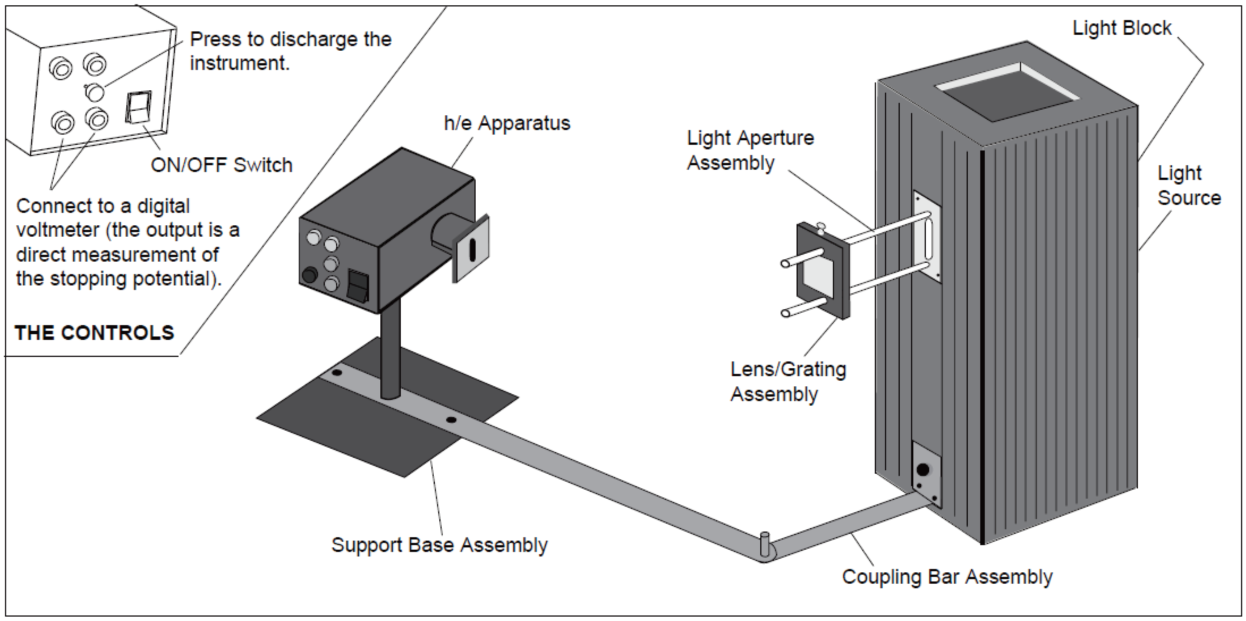

Figure 29. Equipment Set-up

2. Tilt the light shield of the apparatus (shown in Figure 30) out of the way to reveal the white photodiode mask inside the Apparatus.

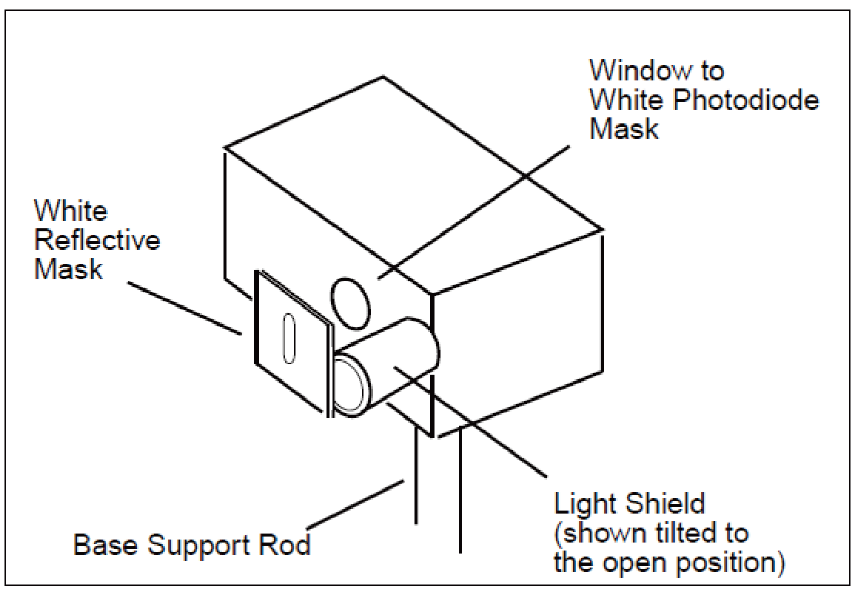

Figure 30. h/e *Light Shield*

3. Slide the lens/grating assembly forward and back on its support rods until you achieve the sharpest image of the aperture centered on the hole in the photodiode mask. Secure the lens/grating by tightening the thumbscrew.

4. Adjust the h/e apparatus so that only one of the colors falls upon the mask of the photodiode. There must be no overlap from adjacent spectral maxima. If you select the green or yellow line, place the corresponding colored filter over the white reflective mask on the h/e apparatus. *(These filters limit the frequencies of light from entering the h/e apparatus by preventing ambient room light from interfering with lower energy yellow and green light and masking the true result. They also block the higher frequency ultraviolet light from the higher order spectra which may overlap with lower orders of yellow and green.)*
5. Place the variable transmission filter in front of the white reflective mask (and over the colored filter, if one is used) so that light passes through the section marked 100 % and reaches the photodiode. Record the digital voltage meter reading which corresponds to the stopping potential for the photoelectrons emitted from the photodiode using Table 1 below. *(The variable transmission filter consists of computer-generated patterns of dots and lines that vary the intensity (but not the frequency) of the incident light.)* Press the instrument discharge button, release it, and observe how much time is required to recharge the instrument to the maximum voltage.
6. Move the variable transmission filter so that the next section is directly in front of the incoming light. Record the new voltage reading and approximate the time to recharge after the discharge button has been pressed and released.
7. Repeat step 6 until you have tested all five sections of the filter.
8. Repeat the procedure using a second color from the spectrum.
9. Describe the effect that passing different amounts of the same colored light through the variable transmission filter has on the stopping potential and thus the maximum energy of the photoelectrons, as well as the charging time after pressing the discharge button.
10. Describe the effect that different colors of light had on the stopping potential and thus the maximum energy of the photoelectrons. Tabulate your results using Table 2.

Determining the Planck's Constant and the Work Function of the Photodiode

11. Determine the wavelength and frequency of each spectral line. Plot a graph of the stopping potential vs. frequency, using the value of the stopping potential for the 100 % transmission for each color.
12. Draw the best-fit line and determine the *slope* of this line. From this value, calculate the Planck's constant, h, using equation (4) with $e = 1.609 \, x \, 10^{-19}$ C. Determine also the work function, ϕ, of the photodiode by getting the y-*intercept* of the line.

DATA

Table 1

Color	**% Transmission**					**Stopping Potential** *(V)*	**Approx. Charge Time** *(s)*
	100	80	60	40	20		
Yellow							
Green							
Blue							
Violet							
Ultraviolet							

Table 2

Color	**Wavelength** *(nm)*	**Frequency** *($\times 10^{14}$ Hz)*	**Stopping Potential** *(V)*
Yellow	578	5.18672	
Green	546.074	5.48996	
Blue	435.835	6.87858	
Violet	404.656	7.40858	
Ultraviolet	365.483	8.20264	

Planck's Constant (h)

h (theoretical) = 6.626×10^{-34} J·s

h (experimental) =

% error =

Work Function (ϕ) =

IV. EVALUATION

1. Explain the dependence of the stopping potential on the light frequency. How does this relate to the quantum (photon) model of light?
2. Explain why there is a slight drop in the measured stopping potential as the light intensity is decreased.
3. Defend whether this experiment supports a wave or a quantum model of light based on your lab results.
4. Explain the correct analysis of the photoelectric effect developed by Albert Einstein.