Physics Department
Kuwait University EXP. SEVEN
Course 127

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Photoelectric Effect (h/e)

Objective

- To study the photoelectric effect.
- Verify the photon model.
- Determine Plank's constant, *h*.

Theory

In photoelectric emission, light strikes a material, causing electrons to be emitted. The classical wave model predicted that as the intensity of incident light is increased, the amplitude and thus the energy of the wave increase, too. This would then cause more energetic photoelectrons to be emitted. The photon model, however, predicts that higher frequency light would produce higher energy photoelectrons, independent of intensity, while increased intensity would only increase the number of electrons emitted (or photo-electric current).

Einstein applied Planck's theory and explained the photoelectric effect in terms of the photon model using his famous equation for which he received the Nobel prize in 1921:

$$E = h\nu = K_{max} + \phi, \tag{1}$$

where E is the energy supplied by the quantum of light known as a photon, h is Planck's constant, ν is the frequency of the photon, $K_{\max}$ is the maximum kinetic energy of the emitted photoelectrons, and ϕ is the work function, which represents the energy needed to remove the electron from the surface of the material.

When a photon with energy, $h\nu$, is incident upon an electron in the cathode of a vacuum tube, part of its energy (which equals the work function ϕ of the cathode's material) goes for releasing the electron from the atom, and the rest is absorbed by the electron and shows up as kinetic energy, K_{max}. Normally the emitted electrons reach the anode of the tube, and can be measured as a photoelectric current. However, by applying a reverse potential, V, between the anode and the cathode, the photoelectric current can be stopped. K_{max} can be determined, by measuring the minimum reverse potential needed to stop the photoelectrons and reduce the photoelectric current to zero. Relating kinetic energy to stopping potential gives

$$K_{max} = eV, \qquad (2)$$

where e, is the electronic charge. Therefore, using Einstein's equation,

$$h\nu = eV + \phi, \qquad (3)$$

when solved for V, gives

$$V = \left(\frac{h}{e}\right)\nu - \frac{\phi}{e}. \qquad (4)$$

A plot of V versus ν for different frequencies of light results in a straight line, where the V-intercept equal to $-\phi/e$ and the slope is h/e.

In this experiment an h/e apparatus is used to investigate the photoelectric effect. The stopping potential is measured directly at the output of the unit, using a digital multi-meter. The experiment is of two parts. In part one, the relationship between energy, wavelength, and the frequency is investigated, whereas part two examines the effect of the intensity of incident light on the stopping potential of the emitted electrons.

Equipment

- *h/e* apparatus.
- Mercury Vapor Light Source.
- Lens/Grating assembly.
- Digital multimeter.

Procedure

1. Place the h/e Apparatus (Fig. 1) onto the Support Base Assembly.
2. Place the Support Base assembly over the pin on the end of the Coupling Bar assembly.

3. Connect a digital voltmeter (DVM) to the OUTPUT terminals of the h/e Apparatus. Select the 2 V or 20 V range on the meter.

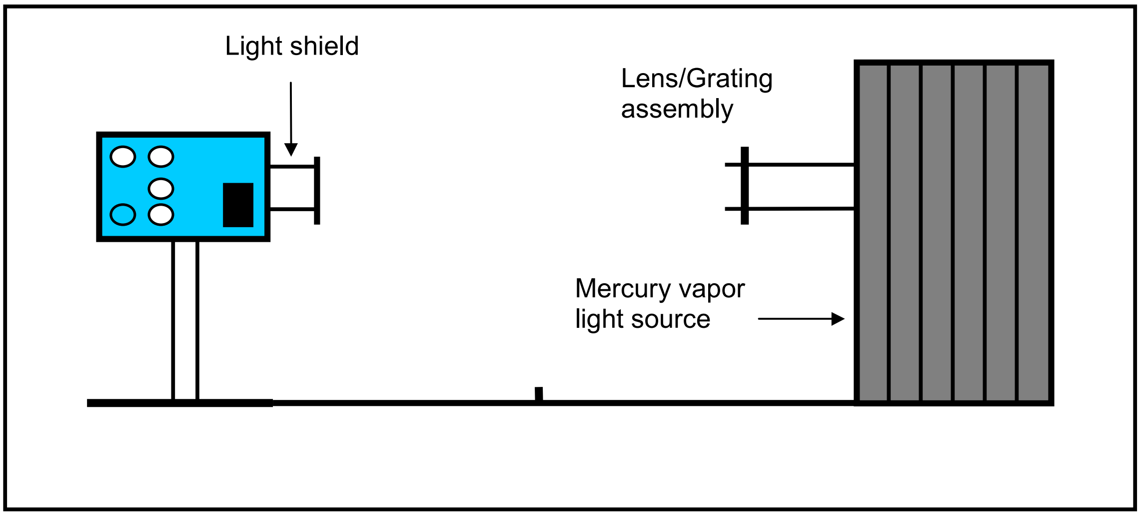

Figure 1: The h/e Apparatus

4. Set the h/e Apparatus directly in front of the Mercury Vapor Light Source. By sliding the Lens/Grating assembly back and forth on its support rods, focus the light onto the white reflective mask of the h/e Apparatus.
5. Roll the light shield of the Apparatus out of the way to reveal the white photodiode mask inside the Apparatus. Rotate the h/e Apparatus until the image of the aperture is centered on the window in the photodiode mask. Then tighten the thumbscrew on the base support rod to hold the Apparatus in place.
6. As in step 4, slide the Lens/Grating assembly back and forth on its support rods, until you achieve the sharpest possible image of the aperture on the window in the photodiode mask. Tighten the thumbscrew on the Lens/Grating assembly and replace the light shield.
7. Turn the power switch ON. Rotate the h/e Apparatus about the pin of the Coupling Bar Assembly until one of the colored lines in the first order shines directly on the slit in the white reflective mask. Rotate the h/e Apparatus on its support base so that the same spectral line falls on the opening in the White Reflective Mask also falls on the window in the photodiode mask.
8. Press the zero button to discharge any accumulated potential in the unit's electronics.
9. Read the output voltage on the digital multimeter.

Part one: (*The Relationship between Energy, Wavelength, and Frequency*)

Procedure

1. Adjust the h/e Apparatus carefully so that only one color from the first order falls on the opening of the mask of the photodiode.
2. For each color in the first order, press the instrument discharge button and release, then, record the stopping potential in Table I.
3. Use the yellow and green colored filters on the reflective mask of the h/e Apparatus when you measure the yellow and green spectral lines.
4. Move to the second order and repeat the process. Record your results in Table II.
5. Plot V vs ν for both tables, form which determine Plank's constant, h, and the work function, ϕ.

Table I

First order color	Wavelength (λ) (nm)	Frequency (ν) $\times 10^{14}$ Hz	Stopping potential (V) Volts
Violet1	365	8.22	
Violet2	405	7.41	
Blue	436	6.88	
Green	546	5.49	
Yellow	578	5.19	

Table II

second order color	Wavelength (λ) (nm)	Frequency (ν) $\times 10^{14}$ Hz	Stopping potential (V) Volts
Violet1	365	8.22	
Violet2	405	7.41	
Blue	436	6.88	
Green	546	5.49	
Yellow	578	5.19	

Part two: (*The effect of the intensity on the stopping potential*)

Procedure

1. Adjust the h/e apparatus so that the Violet1 line falls upon the opening of the mask of the photodiode.
2. Place the variable transmission mask filter in front of the white reflective mask so that the light passes through the section marked 100% and reaches the photodiode.
3. Press the instrument discharge button and release. Record the stopping potential in Table III.
4. Move the variable transmission filter mask to the next section. Record the stopping potential.
5. Repeat step 4 till you have tested all five sections of the filter.

Table III (*Violet1*)

Transmission %	Stopping potential (Volts)
100	
80	
60	
40	
20	

Questions

1. If a photon with energy $E_{ph}=\phi$ is incident on a metal, what will be the speed of the emitted electron?
2. Why are the stopping potentials corresponding to the same colors of the 1^{st} and the 2^{nd} orders almost the same?
3. What does the results of part one of the experiment verify?
4. What does the results of part two of the experiment verify?