



Photoelectric Effect Apparatus

Model No. AP-8209

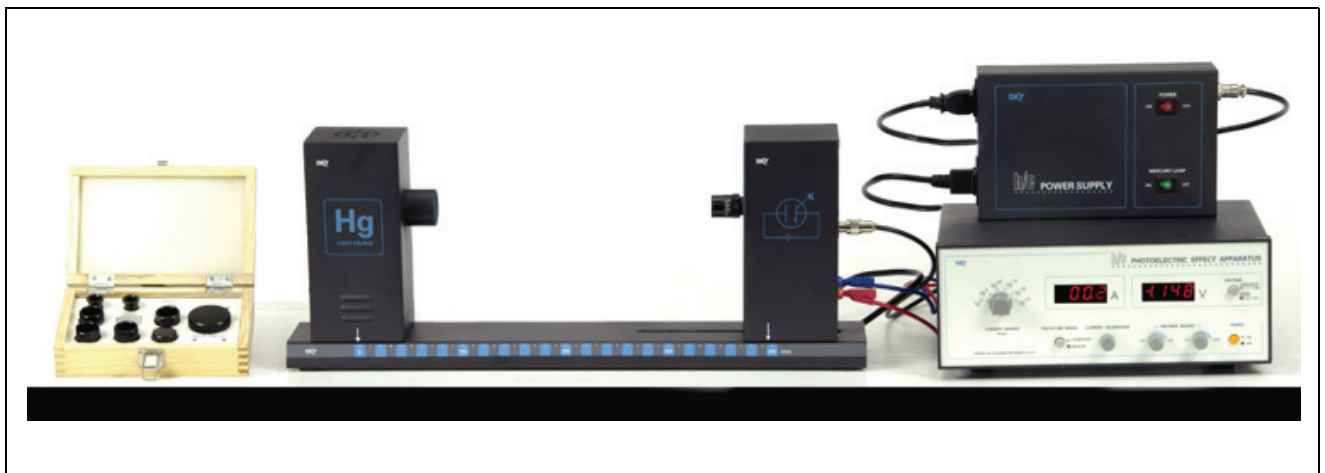


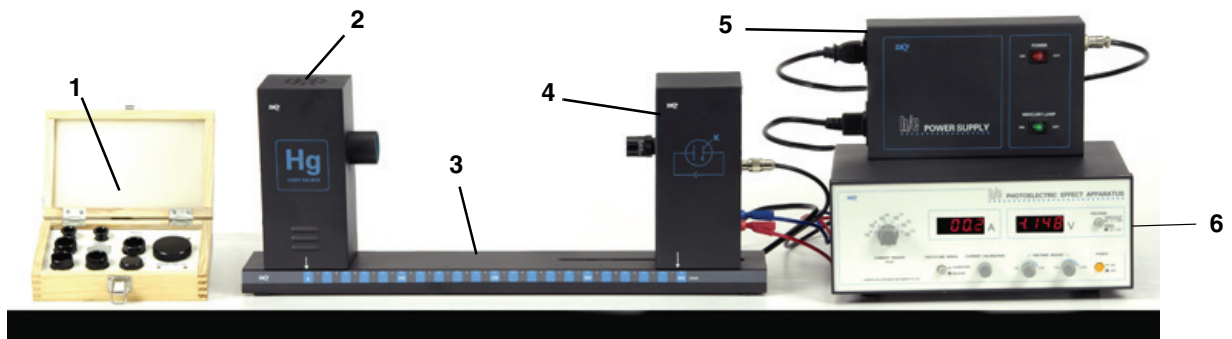
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Equipment List



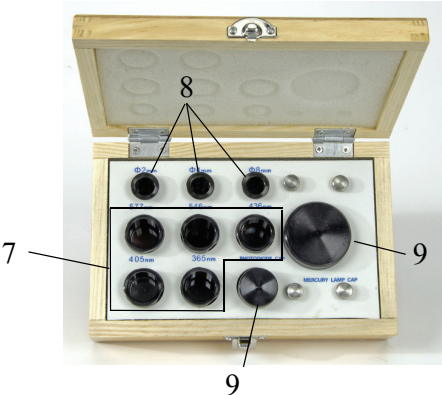
Included Equipment
1. Optical Filters, Apertures, Caps, and Screws
2. Mercury Light Source Enclosure
3. Base
4. Photodiode Enclosure
5. Power Supply
6. Photoelectric Effect Apparatus

Replacement Photodiode: AP-8207

Replacement Mercury Lamp: AP-8208

Cables and Cords
Power Cable for Photoelectric Effect Apparatus
BNC Connector Cable for Photodiode Enclosure
Banana-plug Patch Cords, Red and Blue

Items in the Optical Filters Box
7. Filters: 365 nm, 405 nm, 436 nm, 546 nm, 577 nm
8. Apertures: 2 mm diameter, 4 mm dia., 8 mm dia.
9. Caps: Photodiode, Mercury Lamp



Introduction

The photoelectric effect is the emission of electrons from the surface of a metal when electromagnetic radiation (such as visible or ultraviolet light) of the right frequency shines on the metal. At the time of its discovery, the classical wave model for light predicted that the energy of the emitted electrons would increase as the intensity (brightness) of the light increased.

Instead it was discovered that the energy of the emitted electrons was directly proportional to the frequency of the incident light, and that no electrons would be emitted if the light source was not above a certain threshold frequency. Lower energy electrons were emitted when light with relatively low frequency was incident on the metal, and higher energy electrons were emitted when light with relatively high frequency was incident on the metal.

The AP-8209 Photoelectric Effect Apparatus consists of a mercury light source enclosure, a photodiode tube enclosure, a base, the photoelectric effect test instrument, miscellaneous cords and cables, a power supply for the mercury light source and the test instrument, and a box of apertures, filters, caps, and alignment screws.

The apparatus has several important features:

- The current amplifier has high sensitivity and is very stable in order to improve the accuracy of the measurement.
- The photoelectric tube has low levels of dark current and anode reverse current.
- The optical filters are of high quality in order to avoid an error due to interference between different spectral lines.

Background Information

Many people contributed to the discovery and explanation of the photoelectric effect. In 1865 James Clerk Maxwell predicted the existence of electromagnetic waves and concluded that light itself was just such a wave. Experimentalists attempted to generate and detect electromagnetic radiation and the first clearly successful attempt was made in 1886 by Heinrich Hertz. In the midst of his experimentation, he discovered that the spark produced by an electromagnetic receiver was more vigorous if it was exposed to ultraviolet light. In 1888 Wilhelm Hallwachs demonstrated that a negatively charged gold leaf electroscope would discharge more rapidly than normal if a clean zinc disk connected to the electroscope was exposed to ultraviolet light. In 1899, J.J. Thomson determined that the ultraviolet light caused electrons to be emitted from the metal.

In 1902, Phillip Lenard, an assistant to Heinrich Hertz, used a high intensity carbon arc light to illuminate an emitter plate. Using a collector plate and a sensitive ammeter, he was able to measure the small current produced when the emitter plate was exposed to light. In order to measure the energy of the emitted electrons, Lenard charged the collector plate negatively so that the electrons from the emitter plate would be repelled. He found that there was a minimum “stopping” potential that kept all electrons from reaching the collector. He was surprised to discover that the “stopping” potential, V_s , - and therefore the energy of the emitted electrons - did *not* depend on the intensity of the light. He found that the maximum energy of the emitted electrons *did* depend on the color, or frequency, of the light.

In 1901 Max Planck published his theory of radiation. In it he stated that an oscillator, or any similar physical system, has a discrete set of possible energy values or levels; energies between these values never occur. Planck went on to state that the emission and absorption of radiation is associated with transitions or jumps between two energy levels. The energy lost or gained by the oscillator is emitted or absorbed as a quantum of radiant energy, the magnitude of which is expressed by the equation: $E = h\nu$ where E equals the radiant energy, ν is the frequency of the radiation, and h is a fundamental constant of nature. (The constant, h , became known as Planck's constant.)

In 1905 Albert Einstein gave a simple explanation of Lenard's discoveries using Planck's theory. The new 'quantum'-based model predicted that higher frequency light would produce higher energy emitted electrons (photoelectrons), independent of intensity, while increased intensity would only increase the number of electrons emitted (or photoelectric current). Einstein assumed that the light shining on the emitter material could be thought of as 'quanta' of energy (called photons) with the amount of energy equal to $h\nu$ with ν as the frequency. In the photoelectric effect, one 'quantum' of energy is absorbed by one electron. If the electron is below the surface of the emitter material, some of the absorbed energy is lost as the electron moves towards the surface. This is usually called the 'work function' (W_0). If the 'quantum' is more than the 'work function', then the electron is emitted with a certain amount of kinetic energy. Einstein applied Planck's theory and explained the photoelectric effect in terms of the quantum model using his famous equation for which he received the Nobel prize in 1921: $E = h\nu = KE_{max} + W_0$



Albert Einstein

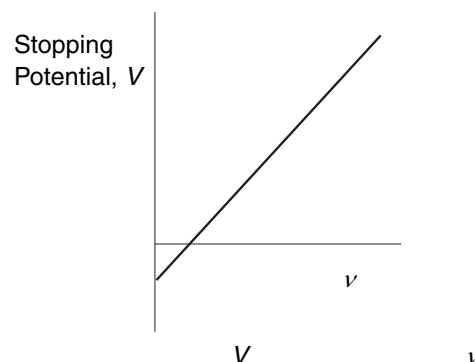
where KE_{max} is the maximum kinetic energy of the emitted photoelectron. In terms of kinetic energy, $KE_{max} = h\nu - W_0$

If the collector plate is charged negatively to the 'stopping' potential so that electrons from the emitter don't reach the collector and the photocurrent is zero, the highest kinetic energy electrons will have energy eV where e is the charge on the electron and V is the 'stopping' potential.

$$eV = h\nu - W_0$$

$$V = \frac{h}{e}\nu - \frac{W_0}{e}$$

Einstein's theory predicts that if the frequency of the incident light is varied, and the 'stopping' potential, V , is plotted as a function of frequency, the slope of the line is h/e (see Figure 1).



Principle of the Experiment

When incident light shines on the cathode (K), photoelectrons can be emitted and transferred to the anode (A). This constitutes a photocurrent. By changing the voltage between the anode and cathode, and measuring the photocurrent, you can determine the characteristic current-voltage curves of the photoelectric tube.

The basic facts of the photoelectric effect experiments are as follows:

- For a given frequency (color) of light, if the voltage between the cathode and anode, V_{AK} , is equal to the stopping potential, V_s , the photocurrent is zero.
- When the voltage between the cathode and anode is greater than the stopping voltage, the photocurrent will increase quickly and eventually reach saturation. The saturated current is proportional to the intensity of the incident light. See Figure 2.
- Light of different frequencies (colors) have different stopping potentials. See Figure 3
- The slope of a plot of stopping potential versus frequency is the value of the ratio, h/e . See Figure 1.
- The photoelectric effect is almost instantaneous. Once the light shines on the cathode, photoelectrons will be emitted in less than a nanosecond.

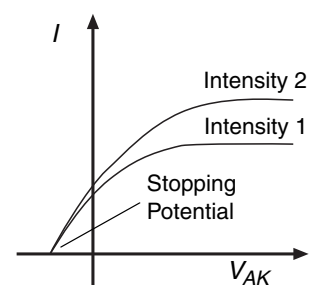
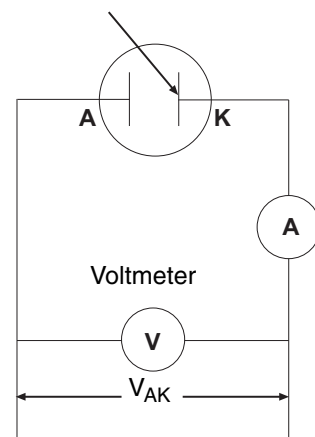


Figure 2: Current vs. Intensity

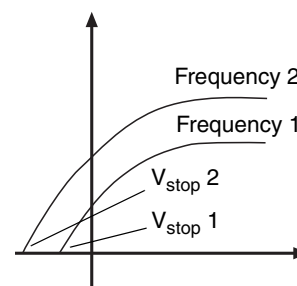


Figure 3: Current vs. Frequency

Basic Setup

Install the Mercury Lamp in the Mercury Light Source Enclosure

- Use a phillips head screwdriver to remove the four small screws that hold the back plate onto the Mercury Light Source enclosure.
- Use a small flat-blade screwdriver to pry the back panel off of the enclosure.

Note: Do not touch the glass envelope of the mercury lamp. Oil and moisture from the skin may diminish the lamp's performance. Use gloves, a clean cloth, or a paper towel to handle the mercury lamp.

- Screw the mercury lamp into the socket inside the enclosure.
- Replace the back panel and screws on the enclosure.



Alignment Screws

The Mercury Light Source has two small alignment screws on opposite corners of its base. The Photodiode enclosure has slightly larger alignment screws installed along the midline of its base.

Mount the Enclosures on the Base

Place the Mercury Light Source enclosure on the base so that the alignment screws go into the matching alignment holes on the base, and the position indicator arrow on the side of the enclosure is aligned with 0 mm on the edge of the base.

Place the Photodiode enclosure on the base so that the alignment screws go into the matching alignment holes on the slot in the base, and the position indicator arrow on the side of the enclosure is aligned with 400 mm on the edge of the base

Connect Cords and Cables

Note: Before connecting any cords or cables, be sure that both switches on the h/e Power Supply are in the OFF position.

- Connect the power cord from the Mercury Light Source enclosure into the receptacle labeled “POWER OUTPUT FOR MERCURY ~220V” on the side of the h/e Power Supply.
- Connect the special DIN-plug-to-DIN-plug power cable between the port on the back of the Photoelectric Effect Apparatus labeled “POWER SUPPLY” and the port on the h/e Power Supply labeled “POWER OUTPUT FOR APPARATUS”. Screw the knurled rings on the plug ends of the cable onto the threaded section of each port.
- Connect the special BNC-plug-to-BNC-plug cable between the port marked “K” on the Photodiode enclosure and the port marked “K” on the back of the Photoelectric Effect Apparatus. Screw the knurled rings on the plug ends of the cable onto the threaded section of each port.
- Connect the red banana-plug patch cord between the port marked “A” on the Photodiode enclosure and the port marked “A” on the back of the Photoelectric Effect Apparatus.
- Connect the blue banana-plug patch cord between the port marked with the ‘down arrow’ (symbol for GROUND) on the Photodiode enclosure and the port marked with the ‘down arrow’ (GROUND) on the back of the Photoelectric Effect Apparatus.
- Connect the power cord between the port on the side of the h/e Power Supply labeled “POWER INPUT ~110V” and an appropriate electrical outlet (Note: For the 220 volt model, connect the cord between the port labeled “POWER INPUT ~220V” and an appropriate electrical outlet.)

Alignment screws

Alignment holes

Alignment screws

Alignment holes

Note: These three cords will be disconnected during calibration. You do not need to turn off the power from the Power Supply when you disconnect and then reconnect these three cords

h/e Photoelectric Effect Apparatus

The h/e Photoelectric Effect Apparatus has four knobs, three buttons and two digital displays on its front panel, and four ports (labeled A, K, 'down arrow', and POWER SUPPLY) on its back panel. The apparatus measures the photocurrent through the photodiode tube and the voltage across the photodiode tube.

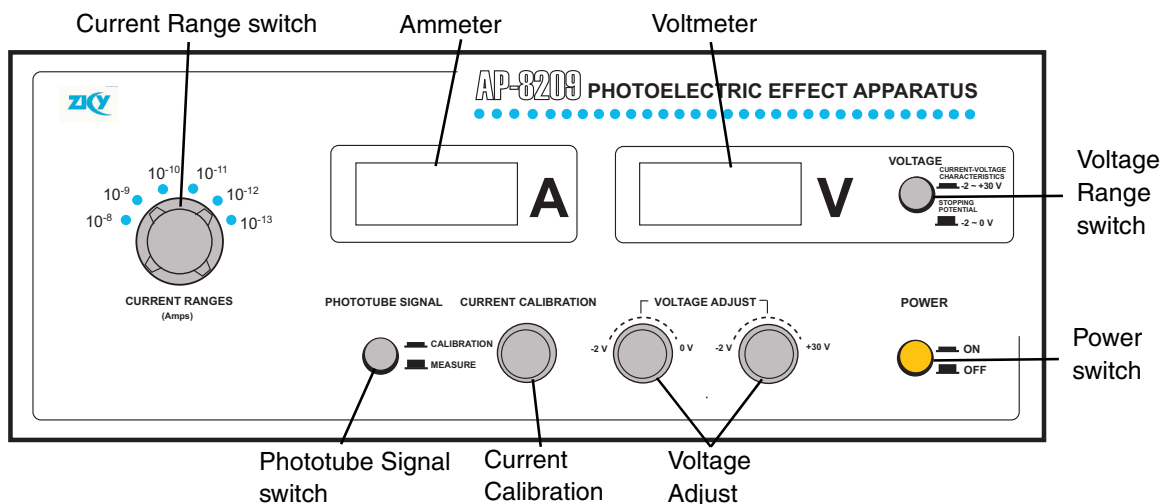


Figure 4: Photoelectric Effect Apparatus

- Current Range switch: Sets the current range for the instrument's current amplifier (10^{-8} to 10^{-13} A).
- Ammeter: Displays the photocurrent through the photodiode tube.
- Voltmeter: Displays potential across the photodiode tube.
- Voltage Range switch: Sets the voltage range as -2 to +30 V for plotting current-voltage characteristics and -2 to 0 V for measuring the stopping potential.
- Power switch: Turns the power to the instrument ON or OFF.
- Voltage Adjust: Sets the potential across the photodiode tube for both voltage ranges.
- Current Calibration: Sets the current through the instrument to zero.
- Phototube Signal switch: Sets the signal from the photodiode tube to CALIBRATION or MEASURE.

Measurement Accuracy

Two factors may affect the measurement accuracy. First, the photocurrent is extremely small. Second, because of the cathode dark current and the anode reverse current, the voltage when the photocurrent is zero is not exactly the stopping potential. (For more information, see [Experiments in Modern Physics](#) by A. Melissinos, copyright 1966, Harcourt Brace Jovanovich, publishers.)

The apparatus has a very sensitive and stable current amplifier so that the small photocurrent can be measured accurately. The photodiode tube has a low level of dark current and anode reverse voltage. In addition, because stopping potential versus frequency is plotted for several spectral lines and the slope of stopping potential versus frequency is used to calculate Planck's constant, the slope method gives an accurate result even if the stopping potential is not exactly accurate.

Experiment 1: Measuring and Calculating Planck's Constant, h

Preparation before measurement

1. Cover the window of the Mercury Light Source enclosure with the Mercury Lamp Cap from the Optical Filters box. Cover the window of the Photodiode enclosure with the Photodiode Cap from the Optical Filters box.
2. On the h/e Power Supply, turn on POWER and MERCURY LAMP. On the Photoelectric Effect Apparatus, push in the POWER button to the ON position.
3. Allow the light source and the apparatus to warm up for 20 minutes.
4. On the apparatus, set the VOLTAGE Range switch to $-2 - 0$ V. Turn the CURRENT RANGES switch to 10^{-13} .
5. To set the current amplifier to zero, first *disconnect* the 'A', 'K', and 'down arrow' (GROUND) cables from the back panel of the apparatus.
6. Press the PHOTOTUBE SIGNAL button in to CALIBRATION.
7. Adjust the CURRENT CALIBRATION knob until the current is zero.
8. Press the PHOTOTUBE SIGNAL button to MEASURE.
9. *Reconnect* the 'A', 'K', and 'down arrow' (GROUND) cables to the back of the apparatus.



Note: It is very important to allow the light source and apparatus to warm up for 20 minutes prior to making any measurements.

Measurement

1. Uncover the window of the Photodiode enclosure. Place the 4 mm diameter aperture and the 365 nm filter onto the window of the enclosure. (See the sidebar note.)
2. Uncover the window of the Mercury Light Source. Spectral lines of 365 nm wavelength will shine on the cathode in the phototube.
3. Adjust the VOLTAGE ADJUST knob until the current on the ammeter is zero.
4. Record the *magnitude* of the stopping potential for the 365 nm wavelength in Table 1.
5. Cover the window of the Mercury Light Source.



Note: Always have a filter on the window of the Photodiode enclosure, and put the cap on the Mercury Light source whenever you change the filter or aperture. Never let the light from the Mercury Light source shine directly into the Photodiode enclosure.

6. Replace the 365 nm filter with the 405 nm filter.
7. Uncover the window of the Mercury Light Source. Spectral lines of 405 nm wavelength will shine on the cathode in the phototube.
8. Adjust the VOLTAGE ADJUST knob until the current on the ammeter is zero.
9. Record the *magnitude* of the stopping potential for the 405 nm wavelength in Table 1.
10. Cover the window of the Mercury Light Source.
11. Repeat the measurement procedure for the other filters. Record the *magnitude* of the stopping potential for each wavelength in Table 1.

Table 1: Stopping Potential of Spectral Lines, 4 mm diameter Aperture

Item	1	2	3	4	5
Wavelength, λ (nm)	365.0	404.7	435.8	546.1	577.0
Frequency, $\nu=c/\lambda$, ($\times 10^{14}$ Hz)	8.214	7.408	6.879	5.490	5.196
Stopping Potential, V (V)					

Calculating

1. Plot a graph of Stopping Potential (V) versus Frequency ($\times 10^{14}$ Hz).

Note: For information on using the DataStudio program to plot the graph, see Appendix B.



2. Find the slope of the best-fit line through the data points on the Stopping Potential (V) versus Frequency ($\times 10^{14}$ Hz) graph.

Note: DataStudio allows you to enter your data as ordered pairs in a Table display and then plot the data in a Graph display.

Note: The slope is the ratio of h/e , so Planck's constant, h , is the product of the charge of the electron ($e = 1.602 \times 10^{-19}$ C) and the slope of the best-fit line.

According to the theory of linear regression, the slope of the Stopping Potential versus Frequency graph can be calculated using the following equation:

$$\text{slope} = \frac{\bar{\nu} \cdot \bar{V} - (\bar{\nu \cdot V})}{\bar{\nu}^2 - \bar{\nu}^2}$$

where $\bar{\nu} = \frac{1}{n} \sum_{i=1}^n \nu_i$, $\bar{\nu}^2 = \frac{1}{n} \sum_{i=1}^n \nu_i^2$, $\bar{\nu} \cdot \bar{V} = \frac{1}{n} \sum_{i=1}^n \nu_i \cdot V_i$, and $\overline{\nu \cdot V} = \frac{1}{n} \sum_{i=1}^n \nu_i \cdot V_i$.

3. Record the calculated slope and use it to calculate the value of Planck's constant, h .

Questions

1. How does your calculated value of h for each different aperture compare to the accepted value, h_0 , 6.626×10^{-34} J s?
2. How does light intensity affect the Stopping Potential?

Experiment 2: Measuring Current-Voltage Characteristics of Spectral Lines - Constant Frequency, Different Intensity

This section outlines the instructions for measuring and comparing the current versus voltage characteristics of one spectral line at three different light intensities.

Preparation for Measurement

1. Cover the window of the Mercury Light Source enclosure with the Mercury Lamp Cap from the Optical Filters box. Cover the window of the Photodiode enclosure with the Photodiode Cap from the Optical Filters box.
2. On the h/e Power Supply, turn on POWER and MERCURY LAMP. On the Photoelectric Effect Apparatus, push in the POWER button to the ON position.
3. Allow the light source and the apparatus to warm up for 20 minutes.
4. On the apparatus, set the VOLTAGE Range Switch to $-2 \text{ --- } +30 \text{ V}$. Turn the CURRENT RANGES Switch to 10^{-11} .
5. To set the current amplifier to zero, first disconnect the 'A', 'K', and 'down arrow' (GROUND) cables from the back panel of the apparatus.
6. Press the PHOTOTUBE SIGNAL button in to CALIBRATION.
7. Adjust the CURRENT CALIBRATION knob until the current is zero.
8. Press the PHOTOTUBE SIGNAL button to MEASURE.
9. Reconnect the 'A', 'K', and 'down arrow' (GROUND) cables to the back of the apparatus.



Note: It is very important to allow the light source and apparatus to warm up for 20 minutes prior to making any measurements.

Measurement - Constant Frequency, Different Intensities

2 mm Aperture

1. Uncover the window of the Photodiode enclosure. Place the 2 mm diameter aperture and the 436 nm filter in the window of the enclosure.
2. Uncover the window of the Mercury Light Source enclosure. A spectral line of 436 nm will shine on the cathode in the Photodiode enclosure.



Note: Always have a filter on the window of the Photodiode enclosure, and put the cap on the Mercury Light source whenever you change the filter or aperture. Never let the light from the Mercury Light source shine directly into the Photodiode enclosure.

3. Adjust the -2 — $+30$ V VOLTAGE ADJUST knob so that the current display is zero. Record the voltage and current in Table 4.
4. Increase the voltage by a small amount (for example, 1 V). Record the new voltage and current in Table 4.
5. Continue to increase the voltage by the same small increment. Record the new voltage and current each time in Table 4. Stop when you reach the end of the VOLTAGE range.

4 mm Aperture

1. Cover the window of the Mercury Light Source enclosure.
2. On the Photodiode enclosure, replace the 2 mm diameter aperture with the 4 mm diameter aperture. Put the 436 nm filter back onto the window.
3. Uncover the window of the Mercury Light Source enclosure. A spectral line of 436 nm will shine on the cathode in the Photodiode enclosure.
4. Adjust the -2 — $+30$ V VOLTAGE ADJUST knob so that the current display is zero. Record the voltage and current in Table 4.
5. Increase the voltage by a small amount (e.g., 1 V) and record the new voltage and current in Table 4. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 4. Stop when you reach the end of the VOLTAGE range

8 mm Aperture

1. Cover the window of the Mercury Light Source enclosure.
2. On the Photodiode enclosure, replace the 4 mm diameter aperture with the 8 mm diameter aperture. Put the 436 nm filter back onto the window.
3. Uncover the window of the Mercury Light Source enclosure. A spectral line of 436 nm will shine on the cathode in the Photodiode enclosure.
4. Adjust the -2 — $+30$ V VOLTAGE ADJUST knob so that the current display is zero. Record the voltage and current in Table 4.
5. Increase the voltage by a small amount (e.g., 1 V) and record the new voltage and current in Table 4. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 4. Stop when you reach the end of the VOLTAGE range.

6. Turn off the POWER on the apparatus. Turn off the MERCURY LAMP power switch and the POWER switch on the power supply. Return the apertures, filters, and caps to the OPTICAL FILTERS box.

Table 4: Current and Voltage of Spectral Lines

$\lambda = 435.8 \text{ nm}$ 2 mm dia.	V (V)													
	$I (\times 10^{-11} \text{ A})$													
$\lambda = 435.8 \text{ nm}$ 4 mm dia.	V (V)													
	$I (\times 10^{-11} \text{ A})$													
$\lambda = 435.8 \text{ nm}$ 8 mm dia.	V (V)													
	$I (\times 10^{-11} \text{ A})$													

Analysis

1. Plot the graphs of Current (y-axis) versus Voltage (x-axis) for the one spectral line, 436 nm, at the three different intensities.

Questions

1. How do the curves of current versus voltage for the one spectral line at three different intensities compare? In other words, how are the curves similar to each other?
2. How do the curves of current versus voltage for the one spectral line at three different intensities contrast? In other words, how do the curves differ from each other.

Notes

Experiment 3: Measuring Current-Voltage Characteristics of Spectral Lines - Different Frequencies, Constant Intensity

This section outlines the instructions for measuring and comparing the current versus voltage characteristics of three spectral lines, 436 nm, 546 nm, and 577 nm, but with the same light intensity.

Preparation for Measurement

1. Cover the window of the Mercury Light Source enclosure with the Mercury Lamp Cap from the Optical Filters box. Cover the window of the Photodiode enclosure with the Photodiode Cap from the Optical Filters box.
2. On the h/e Power Supply, turn on POWER and MERCURY LAMP. On the Photoelectric Effect Apparatus, push in the POWER button to the ON position.
3. Allow the light source and the apparatus to warm up for 20 minutes.
4. On the apparatus, set the VOLTAGE Range Switch to $-2 \text{ --- } +30 \text{ V}$. Turn the CURRENT RANGES Switch to 10^{-11} .
5. To set the current amplifier to zero, first disconnect the 'A', 'K', and 'down arrow' (GROUND) cables from the back panel of the apparatus.
6. Press the PHOTOTUBE SIGNAL button in to CALIBRATION.
7. Adjust the CURRENT CALIBRATION knob until the current is zero.
8. Press the PHOTOTUBE SIGNAL button to MEASURE.
9. Reconnect the 'A', 'K', and 'down arrow' (GROUND) cables to the back of the apparatus.

Measurement - Different Frequencies, Constant Intensity

436 nm Wavelength

1. Uncover the window of the Photodiode enclosure. Place the 4 mm diameter aperture and the 436 nm filter in the window of the enclosure.
2. Uncover the window of the Mercury Light Source enclosure. A spectral line of 436 nm will shine on the cathode in the Photodiode enclosure.
3. Adjust the $-2 \text{ --- } +30 \text{ V}$ VOLTAGE ADJUST knob so that the current display is zero. Record the voltage and current in Table 4.



Note: Always have a filter on the window of the Photodiode enclosure, and put the cap on the Mercury Light source whenever you change the filter or aperture. Never let the light from the Mercury Light source shine directly into the Photodiode enclosure.

4. Increase the voltage by a small amount (for example, 1 V). Record the new voltage and current in Table 5.
5. Continue to increase the voltage by the same small increment. Record the new voltage and current each time in Table 5. Stop when you reach the end of the VOLTAGE range.

546 nm Wavelength

1. Cover the window of the Mercury Light Source enclosure.
2. On the Photodiode enclosure, replace the 436 nm filter with the 546 nm filter.
3. Uncover the window of the Mercury Light Source enclosure. A spectral line of 546 nm will shine on the cathode in the Photodiode enclosure.
4. Adjust the -2 — $+30$ V VOLTAGE ADJUST knob so that the current display is zero. Record the voltage and current in Table 5.
5. Increase the voltage by a small amount (e.g., 1 V) and record the new voltage and current in Table 5. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 5. Stop when you reach the end of the VOLTAGE range

577 nm Wavelength

1. Cover the window of the Mercury Light Source enclosure.
2. On the Photodiode enclosure, replace the 546 nm filter with the 577 nm filter.
3. Uncover the window of the Mercury Light Source enclosure. A spectral line of 577 nm will shine on the cathode in the Photodiode enclosure.
4. Adjust the -2 — $+30$ V VOLTAGE ADJUST knob so that the current display is zero. Record the voltage and current in Table 5.
5. Increase the voltage by a small amount (e.g., 1 V) and record the new voltage and current in Table 5. Continue to increase the voltage by the same small increment and record the new voltage and current each time in Table 5. Stop when you reach the end of the VOLTAGE range.
6. Turn off the POWER on the apparatus. Turn off the MERCURY LAMP power switch and the POWER switch on the power supply. Return the apertures, filters, and caps to the OPTICAL FILTERS box.

Table 5: Current and Voltage of Spectral Lines

$\lambda = 435.8 \text{ nm}$ 4 mm dia.	V (V)												
	I ($\times 10^{-11} \text{ A}$)												
$\lambda = 546.1 \text{ nm}$ 4 mm dia.	V (V)												
	I ($\times 10^{-11} \text{ A}$)												
$\lambda = 577.0 \text{ nm}$ 4 mm dia.	V (V)												
	I ($\times 10^{-11} \text{ A}$)												

Analysis

1. Plot the graphs of Current (y-axis) versus Voltage (x-axis) for the three spectral lines, 436 nm, 546 nm, and 577 nm, at the one intensity.

Questions

1. How do the curves of current versus voltage for the three spectral lines at a constant intensity compare? In other words, how are the curves similar to each other?
2. How do the curves of current versus voltage for the three spectral lines at a constant intensity contrast? In other words, how do the curves differ from each other.

<p>Notes</p>

Appendix A: Specifications

Item	Description
Current Amplifier	10^{-8} to 10^{-13} A, in six ranges, 3-1/2 digit display. Zero drift: $\leq \pm 0.2\%$ of full range reading in 30 minutes at the range of 10^{-13} A (after 20 minute warm-up).
Voltage Output for Photoelectric Tube	Voltage adjustment: -2 — $+2$ V and -2 — $+30$ V (two ranges), 3-1/2 digit display. Stability: $\leq 0.1\%$
	Spectral response range: 300–700 nm Minimum cathode sensitivity: $\geq 1 \mu\text{A/Lm}$ Anode: nickel ring Dark current: $\leq 2 \times 10^{-13}$ A ($-2\text{V} \leq V_{AK} \leq 2\text{V}$)
	Five filters with central wavelengths of 365.0, 404.7, 435.8, 546.1, and 578.0 nm
Mercury lamp	
Measuring error	For Plank's constant, within 3%, typical

Appendix B: DataStudio Graphing Instructions

The instructions below outline a method for using DataStudio to plot graphs of Stopping Potential versus Frequency or Current versus Voltage. For information on the latest version of DataStudio, go to the PASCO web site (www.pasco.com).

Procedure

PART 1: Open a new DataStudio file.

DataStudio. When the **Welcome to DataStudio** screen opens, select '**Enter Data**'. An empty Table display with columns for X and Y data and an empty Graph display with X- and Y- axes will open. Click the **Summary** button in the toolbar to open the **Summary** list.



OR

If the

'New Empty Data Table

Summary list will open. Double-click the Graph display

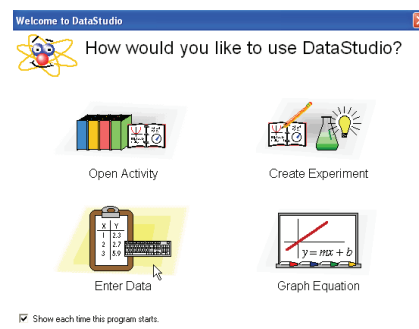
icon in the bottom half of the **Summary** list, or select '**Add Display**

Experiment

screen does not appear, select

Experiment

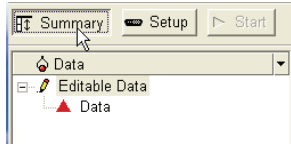
Graph



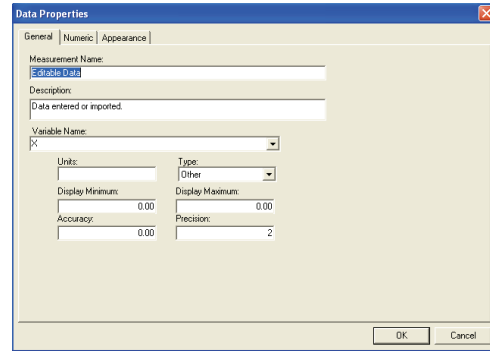
Welcome to DataStudio

PART 2: Create labels for variables and units.

Editable Data **Summary**
Data Properties



Under 'Measurement Name' **Data Properties**
Stopping Potential versus Frequency for Experiment 1.
Under 'Variable Name' **X** **Frequency**
Units **x10^14 Hz**
Variable Name, use the menu button (down arrow) to
open the menu and select 'Y'
Stopping Potential **Variable Name** **V**
Units
OK **Data Properties**



Data Properties



Select 'Y' in the 'Variable Name' menu

PART 3: Enter X- and Y- data into the Table display.

first row of the Table display using the following pattern:
<X- data> TAB <Y-data> RETURN.

Enter the rest of the ordered pairs of Frequency and Stopping Potential using the same pattern. Remember to press RETURN after the last datum is entered.

As the ordered pairs are entered they will be plotted in the Graph display.

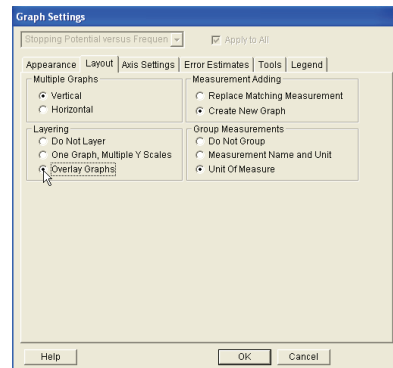
In the Summary list, slowly double-click 'Data' (click-pause-click) to highlight 'Data'. Enter an appropriate label (e.g., 4 mm aperture) for the entered data.

PART 5: Analyze the Data.

In the Graph display, click the 'Fit' menu and select 'Linear Fit'. In the legend box that opens, the value of 'm' is the slope of the best fit line for your data.

To plot more runs of data, select 'Overlay Graphs' from the 'Layering' menu and repeat the procedure (PART 2 to PART 5).

In order to have the runs of data appear on the same plot in the Graph display, double-click the Graph display to open the Graph Settings window. Under the 'Layering' tab, click 'Overlay Graphs'. Click 'OK' to close the window.



Overlay Graphs

Appendix C: Technical Support, Copyright, Warranty

For assistance with the h/e Photoelectric Effect Apparatus (AP-8209) or any other PASCO products, contact PASCO as follows:

Address: PASCO scientific
 10101 Foothills Blvd.
 Roseville, CA 95747-7100
 Phone: (916) 786-3800
 FAX: (916) 786-7565
 Web: www.pasco.com
 Email: support@pasco.com

Copyright Notice

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Warranty

For a description of the product warranty, see the PASCO catalog.

Appendix D: Teacher's Notes

Sample Data

Experiment 1: Measuring and Calculating Planck's Constant

The illustration shows typical data for Stopping Potential versus Frequency with the 4 mm diameter aperture.

The slope value of $0.406 \text{ V}/10^{14} \text{ Hz}$ gives a value for Planck's constant of

$h = 6.504 \times 10^{-34} \text{ J s}$. This value has a 1.8% difference with the accepted value

$h_0 = 6.626 \times 10^{-34} \text{ J s}$.

The following table shows typical data for Stopping Voltage of Spectral Lines for the 4 mm diameter aperture.

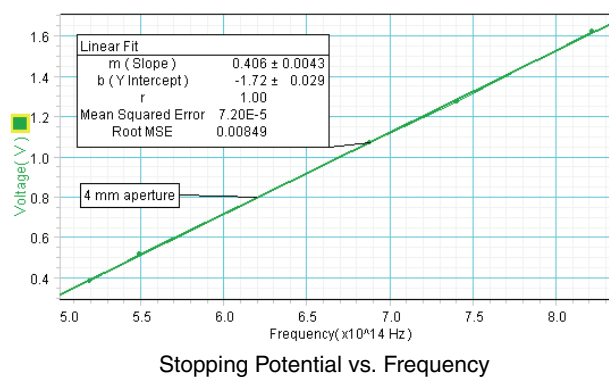


Table 6: Stopping Potential of Spectral Lines, 4 mm diameter Aperture

Item	1	2	3	4	5
Wavelength, λ (nm)	365.0	404.7	435.8	546.1	577.0
Frequency, $\nu=c/\lambda$, ($\times 10^{14}$ Hz)	8.214	7.408	6.879	5.490	5.196
Stopping Potential, V (V)	1.622	1.274	1.068	0.518	0.384

The next two tables show typical data for Stopping Potential of Spectral Lines for the 2 mm and 8 mm diameter apertures.

Table 7: Stopping Potential of Spectral Lines, 2 mm diameter Aperture

Item	1	2	3	4	5
Wavelength, λ (nm)	365.0	404.7	435.8	546.1	577.0
Frequency, ν , ($\times 10^{14}$ Hz)	8.214	7.408	6.879	5.490	5.196
Stopping Potential, V (V)	1.596	1.253	1.053	0.514	0.382

Table 8: Stopping Potential of Spectral Lines, 8 mm diameter Aperture

Item	1	2	3	4	5
Wavelength, λ (nm)	365.0	404.7	435.8	546.1	577.0
Frequency, ν , ($\times 10^{14}$ Hz)	8.214	7.408	6.879	5.490	5.196
Stopping Potential, V (V)	1.652	1.299	1.081	0.526	0.390

Experiment 2: Measuring Current-Voltage Characteristics of Spectral Lines - Constant Frequency, Different Intensity

The illustration shows typical data for current versus voltage for a single spectral line (435.8 nm) with three different apertures.

The next table shows typical data for current versus voltage for a constant frequency and three different apertures.

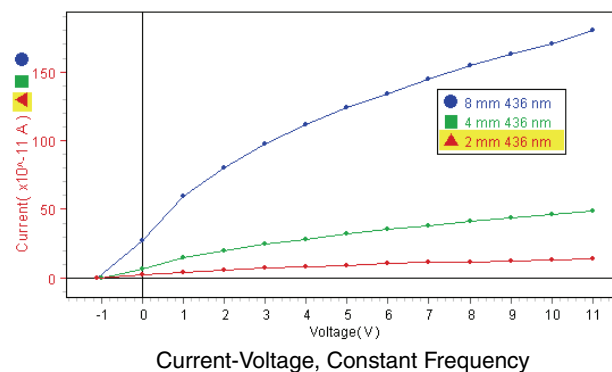


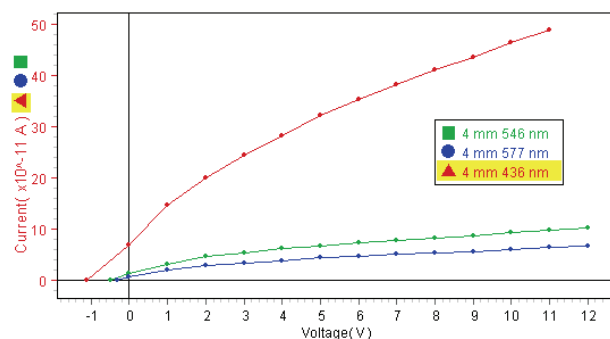
Table 9: Current and Voltage, Constant Frequency, Different Apertures

$\lambda = 435.8 \text{ nm}$ 2 mm dia.	V (V)	-1.1	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10
	I ($\times 10^{-11} \text{ A}$)	0.0	2.2	4.4	5.9	7.2	8.3	9.4	10.4	11.2	11.9	12.6	13.3
$\lambda = 435.8 \text{ nm}$ 4 mm dia.	V (V)	-1.1	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10
	I ($\times 10^{-11} \text{ A}$)	0.0	6.8	14.7	19.9	24.5	28.2	32.1	35.2	38.2	41.2	43.5	46.4
$\lambda = 435.8 \text{ nm}$ 8 mm dia.	V (V)	-1.1	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10
	I ($\times 10^{-11} \text{ A}$)	0.0	27.2	59.7	79.9	97.7	111.6	123.8	133.7	144.5	154.4	162.9	170.4

Experiment 3: Measuring Current-Voltage Characteristics of Spectral Lines - Constant Aperture, Different Frequencies

The illustration shows typical data for current versus voltage for a three spectral lines (435.8 nm, 546.1 nm, 577.0 nm) with the 4 mm diameter aperture.

The next table shows typical data for current versus voltage for a constant aperture and three different frequencies.

**Table 10: Current and Voltage, Different Frequencies, Constant Aperture**

$\lambda = 435.8 \text{ nm}$ 4 mm dia.	V (V)	-1.1	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10
	I ($\times 10^{-11} \text{ A}$)	0.0	6.8	14.7	19.9	24.5	28.2	32.1	35.2	38.2	41.2	43.5	46.4
$\lambda = 546.1 \text{ nm}$ 4 mm dia.	V (V)	-0.5	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10
	I ($\times 10^{-11} \text{ A}$)	0.0	1.3	3.1	4.5	5.3	6.1	6.6	7.2	7.8	8.2	8.7	9.2
$\lambda = 577.0 \text{ nm}$ 4 mm dia.	V (V)	-0.3	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10
	I ($\times 10^{-11} \text{ A}$)	0.0	0.5	2.0	2.8	3.3	3.8	4.3	4.7	5.0	5.3	5.6	5.9

Questions: Experiment 1 - Planck's Constant

1. How does your calculated value of h compare to the accepted value?

The calculated value of h for the 4 mm diameter aperture is within 1.8% of the accepted value of h . Student answers will vary.

2. What do you think may account for the difference – if any – between your calculated value of h and the accepted value?

Student answers will vary. One possible reason for the difference is this: Because the photocurrent is so small, it is somewhat difficult to set the VOLTAGE ADJUST knob to the precise value of stopping potential that will cause the photocurrent to be zero. In addition, nearby electronic devices such as computer monitors may influence the sensitive meters in the apparatus.

3. How can you find the Work Function from the graph of Stopping Potential versus Frequency?

The work function divided by the charge of the electron, e , is the y-intercept on the graph. Multiply the value of the y-intercept by e to find the value of the work function, W_0 .

Extension Questions:

1. How does your calculated value of h for each different aperture compare to the accepted value, h_0 , 6.626×10^{-34} J s?

Answers will vary.

2. How does light intensity affect the Stopping Potential?

Light intensity does not appreciably affect the Stopping Potential?

Questions: Experiment 2 - Constant Frequency

1. How do the curves of current versus voltage for the one spectral line at three different intensities compare? In other words, how are the curves similar to each other?

The current versus voltage curves for one spectral line and three different intensities are similar in that the stopping potential, -1.1 V, is the same for all three curves. The curves have the same overall shape.

2. How do the curves of current versus voltage for the one spectral line at three different intensities contrast? In other words, how do the curves differ from each other.

The current versus voltage curves for one spectral line and three different intensities are different in the following way: The amount of photocurrent increases as the size of the apertures increase. Increased intensity increases the amount of photocurrent.

Questions: Experiment 3 - Constant Intensity

1. How do the curves of current versus voltage for the three spectral lines at a constant intensity compare? In other words, how are the curves similar to each other?

The current versus voltage curves have similar overall shapes.

2. How do the curves of current versus voltage for the three spectral lines at a constant intensity contrast? In other words, how do the curves differ from each other.

The current versus voltage curves differ in that each curve has a different stopping potential. The stopping potentials increase as the frequency increases (or wavelength decreases).

Appendix E: Product End of Life Disposal Instructions

Product End of Life Disposal Instructions:

This electronic product is subject to disposal and recycling regulations that vary by country and region. It is your responsibility to recycle your electronic equipment per your local environmental laws and regulations to ensure that it will be recycled in a manner that protects human health and the environment. To find out where you can drop off your waste equipment for recycling, please contact your local waste recycle/disposal service, or the place where you purchased the product.



The European Union WEEE (Waste Electronic and Electrical Equipment) symbol (above) and on the product or on its packaging indicates that this product must not be disposed of in a standard waste container.

Mercury Bulb Disposal Instructions:

Mercury Bulbs contain chemicals that, if released, may affect the environment and human health. Mercury Bulbs should be collected separately for recycling, and recycled at a local hazardous material disposal location adhering to your country and local government regulations. To find out where you can drop off your waste Mercury Bulbs for recycling, please contact your local waste disposal service, or the place where you purchased the product.