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The Photoelectric Effect Phy 344

Introduction:

Two metal plates with a vacuum between them can usually be thought of as a nearly ideal capacitor: if a DC voltage is applied between them, both plates are charged but no current flows.

This simple picture breaks down if one of the plates is heated; a current will flow between the plates when the unheated plate (or "anode") is at a positive potential relative to the heated "cathode;" if the potential is negative, relatively little current flows. This remarkable behavior is now understood in terms of the "thermionic" emission of negatively charged electrons from the cathode; the temperature assists electrons in leaving the cathode. The arrangement of two electrodes is called a "diode," although most electrical engineers think of a diode as any device with the special electrical properties just described.

Even when the cathode is not heated, a current will flow in the vacuum diode if the cathode is illuminated by light; the discovery is called *photoelectric effect*. Careful measurements of the dependence of the photocurrent upon the intensity of the light and upon its color defied rationalization in terms of the usual picture of light as an electromagnetic traveling wave. Albert Einstein discovered in 1905 that he could explain them by assuming that light consists of particles *or photons;* Einstein received the Nobel prize for this discovery in 1922.

Objectives

- Learn to wire and operate the vacuum photodiode used for photoelectric effect measurements.
- Learn to operate the mercury arc lamp, and become familiar with the spectrum emitted by this lamp.
- Learn to use interference and other spectral filters; achieve a qualitative understanding of the operation of interference filters.
- Measure the current-voltage relationship of the photodiode for several intensities of monochromatic illumination. Achieve a qualitative understanding of this relationship, and assess whether a "stopping potential" can be determined from the measurements.

- Measure the dependence of the stopping potential upon the wavelength of monochromatic illumination. Assess whether these measurements agree with Einstein's theory for the photoelectric effect, and obtain an estimate of the ratio h/e of Planck's constant h to the charge of an electron e.

Suggested Reading: Copies are kept in file.

1. Read a discussion of the photoelectric effect in any elementary physics text; one possibility is the text by T. R. Sandin, *Essentials of Modern Physics* (Addison-Wesley, Reading, 1987), pp. 77-85. Be prepared to discuss why this effect was important in establishing that light consists of photons.

2. The properties of arc lamps are discussed briefly in E. U. Condon and Hugh Odishaw, *Handbook of Physics, Second Edition* (McGraw Hill, 1967), pp. 6-57 - 6-64. See also the materials furnished by Osram, Inc., a manufacturer of arc lamps.

3. A simple introduction to vacuum diodes is given in the book, *Introduction to Electronics,* Theodore Korneff (Academic, New York, 1973), pp. 111-117.

4. Interference filters are discussed in elementary optics books such as Francis A. Jenkins and Harvey E. White, *Fundamentals of Optics, Fourth Edition* (McGraw Hill, New York, 1976), pp. 311-312. See also the materials furnished by MicroCoatings Laboratory, a manufacturer of interference filters.

Suggested Apparatus:

1. Arc lamp power supply. Gates, Inc. model 12S; manual filed under "Gates."

2. Mercury arc lamp. Osram, Inc. Hg/100 mercury arc lamp for use with Gates power supply. Technical information is on file under "Osram."

3. Picoammeter for measurement of photodiode current. Keithley, Inc. model 485 picoammeter. Manual on file under Keithley.

4. DC power supply for photodiode.

5. Photodiode. Leybold model 558 78 housing containing Pressler 451 SUMV/GKV vacuum diode. Instructions are on file under Leybold. Note the two ouput leads are connected to the anode (+) and the top plug on the housing is connected to the cathode (-).

6. Multimeter for measurement of photodiode voltage. Keithley model 169; see file under “Keithley.”

7. Potentiometer for varying photodiode voltage. Clarostat 100 kilohm ten-turn potentiometer mounted on aluminum stand with banana jacks. No file.

8. Optical filters, some transmission and some interference. The later pass only specific frequences. They have aluminum frames and the wavelength transmitted is inscribed in the lower right-hand corner.

9. Optical rail and mounts for arc lamp, filters, and diodes. No file.

10. Hood for lamp and photodiode, **required.**

Safety Considerations: The only clear hazard from this apparatus is overexposure to the mercury arc lamp, which generates ultraviolet light. Please **do not look directly at this lamp or allow your skin to be continuously exposed to the direct beam.** I notice that I get slightly sunburned after working with the apparatus for awhile; I recommend that you expose yourself to as little illumination as practicable. the metal shield cage for the apparatus.

The voltages used in this experiment are low enough to be harmless.

Avoiding damage:

- When you turn off the Hg arc lamp, it must be allowed to cool before attempting to restart it. Do not change the switch setting on the front of the Gates power supply when the lamp is on.

- Be careful not to drop the optical filters, etc.. Some of them are surprisingly costly.

Instructions - Arc Lamps and Filters

- Design a circuit that allows you to monitor the current from the photodiode when the lamp is turned on. Have the instructor check your circuit.

- A mercury arc lamp emits light at several, well-defined wavelengths. Turn on the arc lamp. Place the various visible wavelength filters (λ >400 nm) in the collection in front of your eye, and look at the room lights and the window. Try rotating the filters to see what effect the angle of incidence of the illumination has. Record your observations.

Instructions - Stopping Potential Measurement

1. Design a circuit for the external picoammeter, power supply, potentiometer, and voltmeter to measure the dependence of the current I upon the external voltage V applied to the diode.

2. Wire this circuit; have it inspected before turning on anything.

3. Turn on the power supply and meters for your photodiode apparatus. Verify that the diode is measuring a current related to optical illumination - room lights will be sufficient.

4. Using a green filter, make a study of the dependence of the $I-V$ relation of the diode for different illumination intensities from the arc lamp. The simplest way to do this is to vary the distance between the arc lamp and the photodiode. Use the entire voltage range, including both positive and negative voltages. Make fairly careful measurements in the region of the "stoping potential."

5. Make a single graph showing your $I-V$ curves for differing illumination intensities - including the dark!

6. Graph your photocurrent measurements for several voltages as a function of the distance between the source and the photodiode.

Instructions - Wavelength Dependence of Stopping Potential

1. Measure the dependence of the stopping potential upon the frequency of light using as many of the filters as you can. You should use at least one of the interference filters and you can try combinations of the other filters to select wavelength regions.

2. Graph these data. Draw a line on your graph to represent your best fit using the Einstein photoelectric effect model. Estimate h (Planck's constant) from this fit.

Memoranda

- Were your visual observations with the various filters reasonably consistent with the idea that each filter passed only a single color of light?

- Did you understand how the picoammeter and the potentiometer used in your measurements functioned?

- Why do some mercury arc lamps produce light only a well defined wavelengths?
- Was the form of the current-voltage curve you measured consistent with what you anticipated from your readings about a a vacuum diode?
- Was the intensity-dependence of the "stopping potential" consistent with the idea that a photocurrent can be found only with voltages exceeding this potential?
- Did you understand the intensity-dependence of the photocurrent at a given voltage in the diode?
- Were your observations of the stopping potential as a function of the frequency of light consistent with your understanding of Einstein's photoelectric effect model?

Filter Transmissions These filters transmit light around the value listed. You may check the numbers below and the width of the transmission bands or any new filters with a monochrometer. It is a device that allows you to select individual wavelengths. See the instructor if you wish to make a measurement.

Table 1: Transmissions of Filters

Corning Filters		
Number	Color	Marked λ (nm)
2030	Dark Red	662
3480	Dark Orange	608
3482	Light Orange	600
3486	Yellow	557
3385	Yellow	551
3387	Yellow-Green	541
3389	Pale Green	511
5031	Blue	467