Lab 10 (part one): The photoelectric effect and CCD cameras

Modern telescopes do not use film to record images; rather, they employ a silicon chip that will emit an electron when struck by a photon of the proper energy and the free electron will then hit a wire and be recorded as a current running in that wire. These tiny wires form a grid and, thus, when all the different grid wire intersections have their currents measured, those that had a lot of photons will record as a light spot on the final digital image.

The nice aspect of this technology is that it is not susceptible to heat as film, nor is it as fragile as a film emulsion. But what does the phrase “a photon of the proper energy” mean?

Since the late nineteenth century, physicists had observed that when metals were exposed to different wavelength light rays, some colored lights would cause the metal to emit electrons, yet other colors (even if very intense) did not. When light rays were equated to photons (the wave and particle nature of light), the energy of a single photon could be calculated. Thus, a photon had to have sufficient energy to “knock” an electron off of a metal atom; hurling a lot of photons each without sufficient energy was not enough.

Albert Einstein won a Nobel Prize in physics for much of this work.

In this lab, you will measure the photoelectric effect in a more dramatic manner albeit slightly different fashion. You will be measuring the minimum energy an electron needs to cause a material to emit a photon (so, backwards of the photoelectric effect).

The material is a silicon chip “doped” with arsenic and gallium atoms (the supplier of the photons); this device is called an LED, which stands for “light-emitting diode”. The electrons will be supplied by batteries.

Materials needed:

0 – 24 V power supply (or two 1.5 V batteries in series)
various LEDs (encased in clear, not colored, plastic)
variable resistance panel
two multimeters (one will be used as an ammeter, the other as a voltmeter)
various alligator clip wires

Procedure:

Obtain the multimeters. Turn the main setting knob on one of the multimeters to “A”. Connect the black lead to the “COM” plug and the red lead to the “40 mA” plug; this
multimeter is now the **ammeter** (it will read the amount of the electrical current in **milliamps**).

Turn the main setting knob on the other multimeter to direct current “V”. Connect the black lead to the “COM” plug and the red lead to the “V” plug; this multimeter is now the **voltmeter** (it will read the amount of the voltage in **volts**).

Obtain a variable resistance panel and make sure that all of the switches are “off” (down).

Using the alligator clip wires:

Connect the positive end of the battery pack to the black lead of the ammeter.

Connect the red lead of the ammeter to the long “leg” of the LED.

Connect the short “leg” of the LED to the red plug of the variable resistance panel.

Connect the middle black plug of the variable resistance panel to the negative end of the battery pack.

Finally, connect the red lead of the voltmeter to the long “leg” of the LED. Connect the black lead of the voltmeter to the short “leg” of the LED.

At this point the LED light should turn on.

Record the value of the ammeter and voltmeter below:

- **Ammeter reading =** milliamps
- **Voltmeter reading =** volts

Turn on the “4M” switch on the variable resistance panel; “4M” refers to four million ohms of resistance suddenly being switched on in this circuit. The LED light should turn off.

Record the value of the ammeter and voltmeter below:

- **Ammeter reading =** milliamps
- **Voltmeter reading =** volts

What do you notice happened to the current (milliamps)?
How does this make sense in context of what happened to the LED light? In other words, describe the flow of electrons in the circuit after the “4M” resistance switch is turned on.

What change occurred to the voltage?

Start lowering the amount of resistance (for instance, switching off the “4M” and switching on the “400K”) until you get 0.001 A of current flowing through the circuit. It is okay to have more than one resistor switch turned on at a time. Record the ammeter and voltmeter readings when you reach this point:

Ammeter reading = 0.001 milliamps
Voltmeter reading = volts

Dim the lights and observe the LED (you may have to lower the resistance a little more); it should be on.

Does your observation suggest that there is a minimum necessary voltage in order for current to flow through the LED and thus light the light?

In fact, you can turn that “minimum necessary voltage” into a minimum necessary energy for a photon to be emitted. Use the simple formula $E = Vq$, where $E$ is the energy in Joules, $V$ is the minimum necessary voltage in Volts and $q$ is a constant $= 1.6 \times 10^{-19}$ Coulombs to calculate the minimum necessary energy to turn on the LED.

The number that you calculated above illustrates the photoelectric effect.

The equation $E = hc/\lambda$ allows you to calculate the wavelength of light emitted by the LED. $E$ is again the minimum needed energy in Joules (you calculated this in the previous question), $h$ is Planck’s constant, $c$ is the speed of light (use the text’s appendix table of constants!) and $\lambda$ is the wavelength of the emitted photon in meters.

First, algebraically manipulate the equation in the previous paragraph to isolate $\lambda$ on the left side:
Next, plug in the various constant values, along with your energy value to calculate the wavelength of the photon the LED should be emitting.

In what part of the EM spectrum does this photon exist? You may wish to convert meters to nanometers or micrometers for ease of identification.

Look on the package the LED came in; the manufacturer has printed the wavelength on the back of the package. Record this wavelength below. Does this wavelength match the wavelength you calculated above?

Resolve the disparity; in other words, give a reason why the two wavelengths (calculated and printed) do not match.