

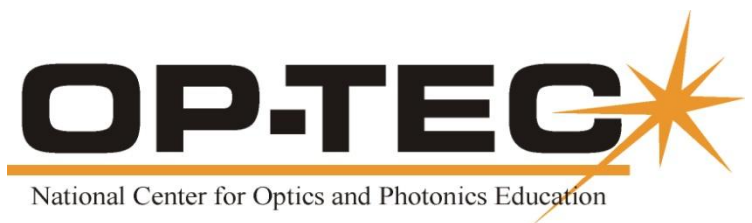
# **Hands-On Green Energy Activities**

## ***Using LEDs and Solar Electric Energy Labs to Interest High School Students in Electro-Optics***

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**June 2011**



This material is based on work supported by the National Science Foundation under Grant No. NSF/DUE 1003199. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

**ABSTRACT:** Photonics is a cutting-edge technology that offers rewarding career opportunities to graduates of AAS programs. It is important for two year colleges that offer AAS education in photonics, to attract capable, interested graduates from local high schools. To do this, colleges must provide electro-optical experiences to high school students that will demonstrate applications of photonics in interesting, relevant situations. One area of high interest is the “green” aspect of energy consumption and conservation. Light Emitting Diodes (LEDs) are new solid state lighting devices that are replacing traditional incandescent bulbs because they are highly efficient and long lasting.

This monograph describes hands-on electro-optic activities, based on LEDs and solar electric devices that have been successfully used with high school students by Indiana University of Pennsylvania (IUP), two-year Northpointe Campus. It includes procedures, equipment requirements, lab activities and their relationship to optical and electro-optical scientific phenomena.

The authors represent OP-TEC: The National Center for Optics and Photonics Education (an NSF ATE National Center of Excellence) and IUP, and OP-TEC Partner College

# **Hands-On Green Energy Activities: Using LEDs and Solar Electric Energy labs to Interest High School Students in Electro-Optics**

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## **Introduction**

Engineering and science technicians are urgently needed in photonics (lasers and electro-optics). Twenty-nine post secondary institutions offer education for technicians in this field; however their enrollments are low because there are not sufficient efforts to attract high school students through interesting, relevant activities in science and technology classes. This paper describes some activities, using light-emitting diodes and solar panels, which have been developed by faculty in the Electro-Optics Program at Indiana University of Pennsylvania. These “green energy” related topics are designed as “hands-on” activities for high school students and teachers and have provided a means for getting students excited about photonics and interested in career opportunities within it.

## **Background**

Photonics, including lasers, optics and electro-optics, has become increasingly important in today’s society. Photonics is an enabling technology which has provided unique applications that have advanced information storage, communication, manufacturing, medical diagnosis/surgery/therapeutic procedures, lighting/displays, and defense/homeland security. The applications of photonics technology into equipment and products play an essential role in our country for maintaining and sustaining economic growth. As new photonics enabled devices come online, it is important to prepare adequate numbers of highly-qualified technicians to manufacture and service them. To meet this demand for technicians, students and parents must be aware of this technology and understand that it offers intellectually challenging and financially rewarding career opportunities.

A national survey of 3,989 U.S. employers in the photonics industry, commissioned by OP-TEC and conducted at the University of North Texas Survey Research Center, estimated 19,785 photonics technicians were employed in the United States in 2009. The survey also identified that an additional 2,100 new jobs would be generated for photonics technicians in this same year and the need will

increase by 5,900 more new jobs from 2010 to 2015 [1]. Hence, there is a significant gap between the employment demand and availability of qualified technicians. To further worsen this situation, the existing twenty-nine, two-year colleges with photonics programs in the U.S. graduate less than 250 techs per year. There is an obvious supply and demand problem that exists now and into the future for photonics technicians and the current capacity of U.S. colleges is not adequate to remedy this problem.

To help meet this high demand for skilled technicians, a 2+2+2 education/ training program in Electro-Optics was launched at Indiana University of Pennsylvania(IUP)'s two-year, Northpointe Campus, offering educational pathways from associate's degrees to bachelor's degrees [2, 3]. The Electro-Optics Career Pathway provides considerable flexibility, allowing multiple entrance and exit points for students to pursue technical and academic education in this emerging field.

The success of this program is dependent on recruiting interested, capable, well-prepared high school graduates before they enter their junior year. Since most high school freshmen and sophomores get little exposure to optics in their science courses and the exposure they get is typically devoid of interesting and useful applications, it was clear these science courses would not work well as recruiting tools for photonics. An alternative was needed. This alternative needed to be interesting to high school students and allow photonics to be presented in an exciting and motivating manner. After some research, IUP found both of these criteria met in the area of "green energy" technology and especially as it relates to light emitting diodes (LEDs) and solar voltaics.

### **Green Energy Realized Through the Use of LEDs and Solar Voltaics**

*Green energy is energy that can be extracted, generated, and/or consumed without any significant negative impact to the environment. (Wikipedia)*

Solid State Lighting: One approach to green energy is through energy conservation, using more efficient devices to produce electric lighting. Solid State Lighting, using Light Emitting Diodes, has been shown to be extremely energy efficient. Lighting (in homes, offices, streets and other public places) consumes almost 30% of the electrical energy generated in this country. The common incandescent light bulb converts less than 25% of the electrical energy it consumes to visible light. Most of the remainder of its consumed energy is converted to heat, which usually must be removed, incurring additional energy consumption. In contrast, light Emitting Diodes can convert over 90% of the energy they consume into useful, visible light. And LEDs have a lifetime in excess of 10,000 hours, as compared to 1000 hours for incandescents.

Beginning in 2012, incandescent lights are being phased out of use in many states. As an interim measure, Compact Fluorescent Light Bulbs (CFLs) are being used to replace incandescent, but they are less efficient and have a shorter life than LEDs; and they contain mercury, which requires special disposal techniques for spent bulbs. Figure 1 shows an LED bulb that has the shape and base of the 125 year-old incandescent design but lasts up to 25 years and is at least 75 percent more efficient than current incandescent bulbs.



Figure 1 An LED bulb.

- **Solar Electric Power Generation:** An excellent source of renewal energy is with electric solar cells (solar voltaics). Currently, Solar electric is only providing approximately 1 % of our nation's energy needs, but it is predicted to increase to 10 % by 2025 [Study: Solar Power Could Provide 10% of U.S. Electricity by 2025 June 25, 2008 [http://apps1.eere.energy.gov/news/news\\_detail.cfm/news\\_id=11835](http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=11835)]. Stimulating this growth is improved conversion efficiencies, lower manufacturing costs for solar panels, additional electric grid lines and more efficient, reliable devices (batteries) to store the solar-generated energy until it is needed for consumption.



Figure 2 Solar panels.

### **IUP's Recruiting Efforts with High School Student**

Just like most postsecondary technical programs, achieving the goal of high enrollments require long term strategies and commitments from college administrators, faculty members and student recruiters to reach high school students, their parents, teachers and school counselors. This is especially true for photonics because most people are unaware of the rewarding career opportunities in this rapidly-evolving discipline. Therefore, recruiting activities must focus on developing awareness and interest in pursuing careers in this field and providing students pathways for getting the education needed to pursue them. IUP has developed and tested many recruiting

activities to reach high school students, including a variety of experiences, such as hands-on experiences, interactions with EO faculty, staff, alumni and current students, on-campus field trips, off-campus field trips, and social activities. These activities are tailored to meet the interest and needs of different groups such as students, teachers/guidance counselors, and parents. These activities include middle and high school classroom presentations and demonstrations, on-campus laboratory experiences, career fairs, parent information sessions, teacher and guidance workshops, and Summer Camps [5, 6]. On average, the IUP Electro-Optics recruiting activities impact over 1,000 students every year.

Our experience has shown that these recruiting activities establish a successful and sustainable secondary-to-postsecondary “pipeline” of students. Effectively integrating these activities into a technical program’s pipeline building efforts may take several years. For example, the process described at IUP has taken five years to put in place. Thus, college faculty and administrators must develop a patient attitude and be prepared to wait years to realize tangible gains from these efforts.



Figure 3 Middle school students conducting on-campus hands-on activities

One key element in building a student pipeline is to provide students the opportunity to come onto a campus and experience college life. These visits allow students to become comfortable with a college’s culture and physical layout and reduce some of the anxiety often associated with transitioning from high school to college. The following five “green technology” activities provide an interesting and educationally beneficial means of promoting these visits. The following five, hands-on activities, developed and tested by IUP, can be used by colleges in summer camps and demonstration events. But they can also be offered to high school STEM programs for use by teachers in their science and technology courses to create interest in electro-optics.

### **LED Based Hands-on Activities**

By making use of multi-color light-emitting diodes (LEDs), photonics concepts can be demonstrated to students of any age. Below are three examples of hands-on activities we developed using LEDs.

#### **1 Measurement of LED Wavelength**

It is an interesting activity to measure the wavelength of LED light using diffraction-grating glasses. Diffraction gratings split light into its constituent wavelengths (colors). By looking at an LED through a grating whose spacing  $d$  is known, and measuring the angle  $\theta$  where the light is imaged, one can measure the wavelength  $\lambda$ . The materials needed for this activity include a 3-V CR-1216 Lithium coin

cell battery, LED lights (single, dual or triple color), a tape measure and grating glasses of 500 line/mm (or any known line spacing value) (see Fig. 4). A grating may be considered a regular array of transmitting "slits" with an opaque space between them. The grating spacing  $d$  is the distance between two adjacent slits.

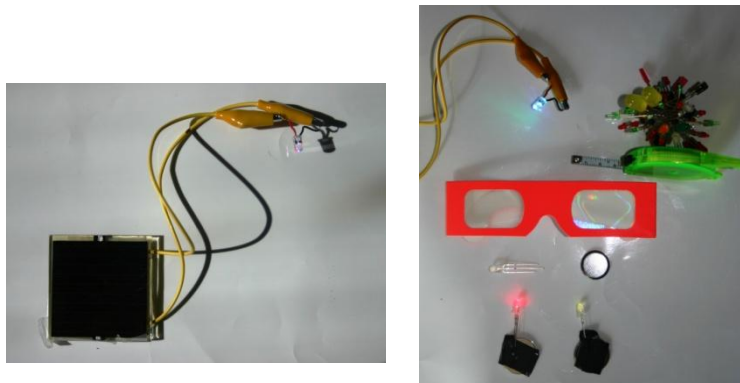


Figure 4 Materials needed for the LED wavelength measurement

This experiment requires students to work in teams of two. Each team connects the LED to the battery according to the LED's polarity. The students then place the LED with the battery on the floor and put on the glasses to observe the diffraction effect. Teams then use the tape measure to measure the distance between the glasses and the LED. To fix the distance, a student could put one eye piece of the glasses on a desk, and then view through the other eye piece the light from the LED that is directly below the glasses (see Fig. 5). While the one student is looking through the eye piece, the other team member marks on a piece of white paper placed under the LED the diffraction images that appear on both sides of the LED.

Instructor note: In general, a student is expected to see several spectral orders on either side of the LED. For the same order, the separation on each side should be the same as measured from the LED. Small differences are tolerable, and may be treated by averaging the left and right deviations. Calculate the deviation angle  $\theta$  for the observed diffraction image using  $\tan \theta = x/D$ , where  $x$  is the measured distance between the LED (the central maximum) and its adjacent diffraction image (the

first order) and  $D$  is the vertical distance between the LED and the diffraction grating glasses.

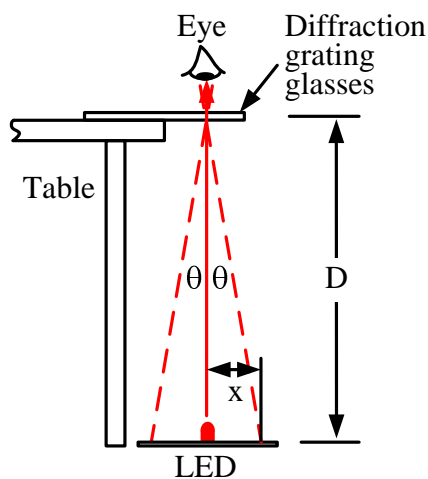


Figure 5 The LED viewed through diffraction grating glasses.

Knowing the deviation angle  $\theta$  and the grating spacing  $d$ , the wavelength of the LED light can be calculated using  $d\sin\theta = m\lambda$  where  $m = 1$  for the first order diffraction image. Repeat the activity using LEDs with different colors and calculate the angular deviations of their diffraction images and then estimate their wavelengths. Compare these results with the nominal LED wavelengths.

## 2. Power Consumption by Commercial LED and CFL Light Bulbs

Choosing more energy-efficient devices is one way homeowners can “go green.” A simple method is to change home lighting from hot incandescent bulbs to compact fluorescent lights (CFLs). But do they really save energy? Even if the CFLs are more energy-efficient, they still add to our pollution problem because of the mercury inside them. Light-emitting diodes (LEDs) could be the answer, but they are typically not available at our local stores. Also there are other considerations that must be addressed. For instance, can they be used with a standard socket? How expensive are they? What are the real electrical power consumptions of so-called “60W” and “100W” CFL and LED light bulbs? These are the questions that are answered during this lab activity [7]. Bulbs, sockets, extension cords, and electrical caps were purchased at local stores. The white base (see Fig. 6) that mounts the socket is shelving cut into square pieces. The LED bulbs with standard bases were found at LED Liquidators. The 90 LED bulbs were \$25 each, and the 60 LED bulbs were \$22 each.

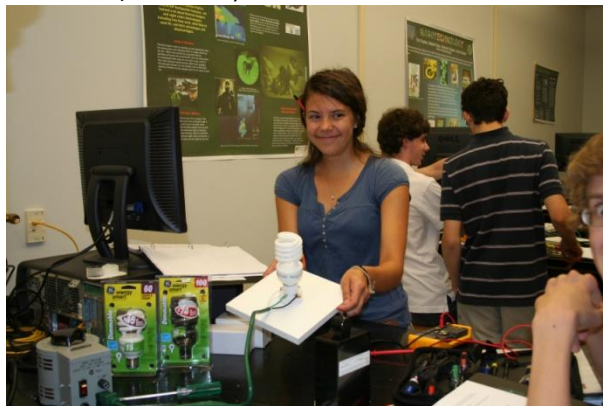


Figure 6 Students working with the “green lab”.

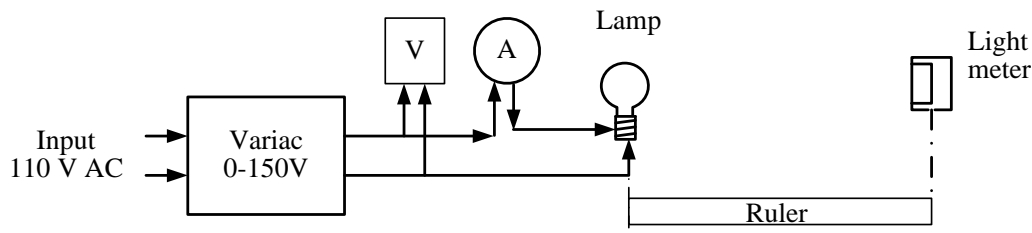


Figure 7 Experimental setup.

The first part of the lab was a comparison of the power consumed by the three types of bulbs. The second part compares the power consumption while the bulbs are set so their luminosities are equal. For this, light meters and variac transformers were required.

Figure 7 shows the experimental set-up. The variac that is connected to a wall plug provides a variable output to the light bulbs. The two digital multi-meters are used to measure both the current and the voltage in the light bulb. (Note that the current measurement is made with a series connection and the voltage measurement requires a parallel connection.) A ruler is used to maintain the same distance from the bulb to the light meter throughout the experiment.

The first part of the lab is to measure the voltage of and current through the lamp. First, the output from the variac was set at 120 V using the digital multi-meter set for a voltage measurement. Next, the current was measured for each bulb using the digital multi-meter set for a current measurement. The experimental data for the power consumption of three different types of light bulbs are shown in Table 1. Power was calculated using  $P = V \cdot I$ , where  $P$  is the power in Watts (W),  $V$  is the voltage in Volts (V), and  $I$  is the current in Amps (A).

The second part of the lab required the measurement of light intensity. Because of the minimum voltage required by the CFLs, they were not used for this experiment. They could not match the brightness of the lower-intensity LEDs at even the lowest voltage settings. Data for the incandescent and LED light bulbs are shown in Table 2. The procedure was exactly the same as the first part of the lab except the variac was turned down for the brighter bulbs and the distance from the bulbs to the meter was held fixed during the light intensity measurements.

Table 1 Power Consumption of Commercial Incandescent, CFL and LED Light Bulbs.

Bulb Type	Voltage (v)	Current (A)	Power (W)
90 W Incandescent	120	0.80	96
100 W CFL	120	0.17	20
90 LED	120	0.075	9.0

52 W Incandescent	120	0.44	53
60 W CFL	120	0.10	12
60 LED	120	0.045	5.4

Table 2 Comparison of Power Usage at Equal Light Intensities for Incandescent and LED light bulbs.

Bulb Type	Light Intensity (Ft Candles)	Voltage (V)	Current (A)	Power (W)
90 W Incandescent	88	88	0.67	59
90 LED	88	120	0.075	9.0
52 W Incandescent	49	95	0.38	36
60 LED	49	120	0.045	5.4

These activities were initially designed for the summer camps we held for high school students. The data obtained reflect considerable energy savings using CFLs, and even more with LEDs. The obvious follow-up to this activity is to have students calculate the costs involved, including details like the life expectancy of these bulbs. The math involved is very basic and can be done by upper elementary school and older students. Safety issues are a concern, especially for elementary students, but the teacher can set up the wiring or just perform the lab as a demonstration.

Another excellent follow-up activity is to test the spectral outputs of the bulbs with simple hand-held spectroscopes. The LED bulb has a wider color spectrum than a CFL. More advanced activities that follow this lab could include a discussion on how the three types of bulbs work and include the disadvantages of the CFLs, such as the limited spectrum, toxic mercury content, and the fluttering of the light intensity. Atomic spectra, basic resistivity and conduction, and semiconductor theory are all excellent topics. Solid-state devices could be taught using band theory and doping for more advanced students. Furthermore, a study of solar energy is highly recommended for students of all ages.

### 3. The Photovoltaic Power Output

A photovoltaic solar electric panel is basically a two terminal p-n junction diode. It generates DC power when it is exposed to sunlight and absorbs photons with energy greater than the band gap energy of the solar cell. A natural question to ask is 'How much power can be provided?'. This experiment shows how to test a solar panel for its current and voltage outputs and how to determine the optimal power point. The electrical power is calculated using  $P = V \cdot I$ .

As shown in Figure 8, the output voltage and current of a solar panel are measured with two digital multi-meters when different power resistors are connected to the solar panel. The material needed for this experiment include a solar cell [10], power resistors of different values, ammeter, voltmeter, and a table used as an illumination source. Alternatively, one digital multi-meter should work if we

know the resistance used because the voltage and current are linked by the resistance  $R$  used in the closed loop by  $V = IR$ . For a larger solar panel, power resistors with high wattage rating are needed to handle the electrical power, or adjustable power resistors (called rheostats). As an example, Table 3 lists the measured voltage and current of a small solar panel illuminated by a table lamp when resistance values of  $\infty$ , 100, 50, 25, 3 and 0 ohms were used. The power is then calculated. Figure 9 shows a typical I-V curve of a solar panel.

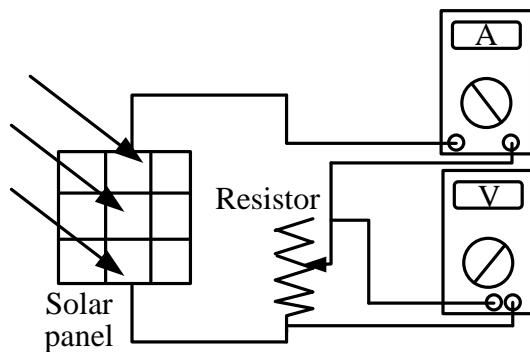


Figure 8 Each power resistor is connected to the solar panel and the voltage and current are measured with the digital multimeters.

Table 3 The voltage, current and power of a solar panel.

Radiated at high optical power density			Radiated at low optical power density		
Voltage (V)	Current (mA)	Power (W)	Voltage (V)	Current (mA)	Power (W)
0.0	153.7	0	0.0	56.5	0
1.452	143.2	0.21	0.584	54.4	0.032
2.344	117.2	0.27	1.028	53	0.054
2.747	95.2	0.26	1.466	51.9	0.076
3.053	74.9	0.23	2.065	49.8	0.10
3.28	52.5	0.17	2.83	45.4	0.13
3.654	17.9	0.07	3.763	20.5	0.077
3.714	9.1	0.03	4	9.8	0.039
3.915	0.0	0.0	4.23	0	0.0

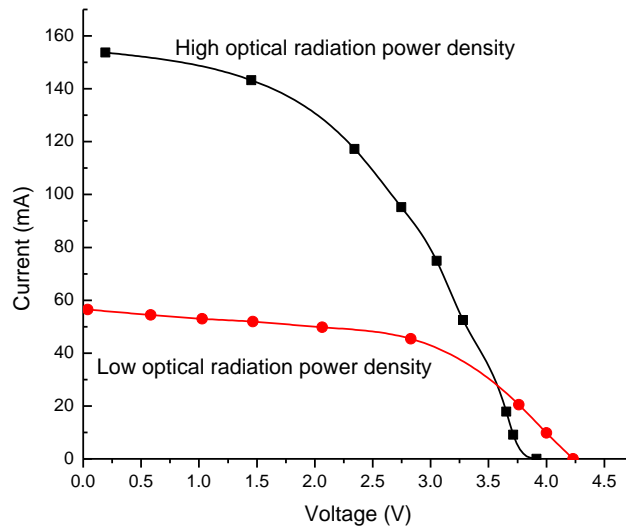


Figure 9 The I-V curves of the solar panel measured at two different optical radiation power densities.

The I-V curves of this solar panel show a characteristic behavior that is common to all solar panels. However, when the radiation power density received by a solar panel changes, the I-V curve also changes. At a higher radiation power density, the output is higher. For a fixed radiation power density, the short circuit provides a maximum current while the open circuit provides a maximum voltage. However, the maximum output power is generated at the point where the product of current and voltage is a maximum. In our case, at the high radiation level, the optimal operating point is at approximately 0.3 watts, corresponding to a load resistance of 20 ohms. As shown in Figure 9, the maximum power point is formed at the 'knee' in the curve where the largest rectangle can be formed beneath the curve.

#### 4. The Solar Powered Street Number Display

In this experiment, solid state lighting and solar panel technologies are integrated to show one possible “green” approach to an old problem, which is poor house number visibility at night. The objective of this activity is to build a “green” house number display powered by a solar panel. The use of a simple dark detecting circuit, solar panel, and blue LEDs, can increase the visibility of the street numbers to private homes and businesses.

Figure 10 is the circuit diagram. The solar panel has a built in tilting bracket to allow proper angle positioning to the sun. Materials needed include a 4.0V-70mA Solar Panel (0.28 watt) made of amorphous silicon; 50 blue LED of 5-mm in diameter operating at 450nm wave length; one 3.2 volt lithium ion, 600 mAh, with initial charge of 6 – 8 hours and runtime of 6-8 hours at full charge. The total material cost is less than \$50. The simple inexpensive dark detecting circuit is built using a solar

panel, one 5k resistor, one 1N914 diode and one 2N3906 transistor. The solar panel senses the presence of light and uses its output to control the transistor, which turns off the LED.

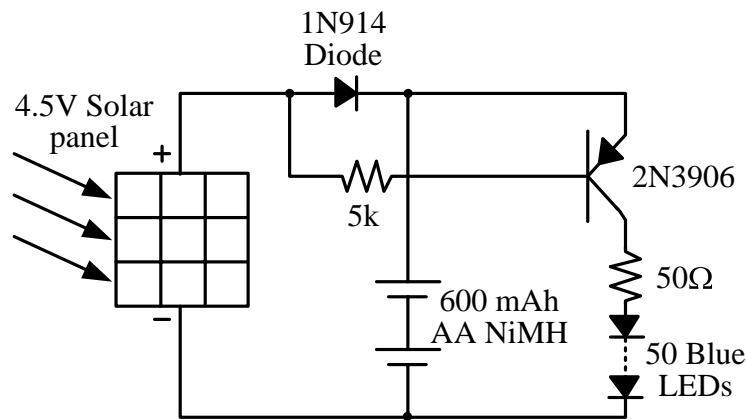


Figure 10 The circuit diagram of a solar powered LED street number display.

The finished project is shown in Figure 11. A simplified solar power dark detector circuit was built separately and placed in front of the main display. The dark detector circuit was on an open circuit board along with (3) 1.5 volt rechargeable batteries in series that were charged by a small solar panel. This unit displayed a single LED numeral and was used to show the inner circuitry of the street number display. The LED display module measures 5" x 10" x 4" in depth and features 3" high numerals. The body of the display is painted flat black with the numerals highlighted in a bright white color with (50) bright 5mm blue LEDs embedded within the house numbers. The unit is water tight to keep out the moisture. This display unit should give many years of continuous service. The lithium ion rechargeable battery will need replaced in approximately (3) years if properly conditioned.

Solar powered LEDs display the house number "436" using the energy stored in an internal (3.2v) lithium ion battery. The battery is charged by the solar panel (4.0V – 70mA) during the day, while the dark detecting circuit switches the LED display on at night. The LEDs will stay illuminated for 6-8 hours at night until the rechargeable battery is depleted. The LED display will automatically be switched off once the solar panel is illuminated by sunlight. The lithium ion battery requires 6-10 hours of daylight to fully recharge.



Figure 11 The completed street number display unit.

The next activity is excellent for embedding within a high school physics course that includes coverage of modern physics concepts. The concepts covered in this activity include Plank's Law, elementary wave mechanics, and basic electricity/RC circuit concepts. Since a main purpose of all these activities is to generate student interest in photonics, make sure students who participate in this activity have academic backgrounds that will allow them to enjoy it and appreciate the measurement of a fundamental physics parameter like Plank's constant. Without this background, students will find the activity rather abstract and uninteresting.

### 5. Computer Based Experiment for Determining Plank's Constant Using Color LEDs

The operation of visible light LED's is very straightforward. However, after the power is switched off, it takes a while for the LED to go off. In this activity, by making use of computer based data acquisition and modeling, we show the voltage across the LED undergoes an exponential decay after the power is switched off. We also describe a new approach for determining Plank's constant using LEDs [8]. The simple experiment can be used as an interactive demonstration or a hands-on activity. In this activity the discharge of a capacitor (C) through an LED in series with a current limiting resistor (R) is monitored. Measuring the voltage across the capacitor during the discharge reveals an exponential decay that approaches a non-zero constant. That constant voltage ( $V_0$ ) is the minimum voltage required for current to flow through the LED. A photon generated by the LED possesses energy  $E = hf = eV_0$  where  $f (= c/\lambda)$  is the frequency of the electromagnetic wave,  $e = 1.6022 \times 10^{-19}$  C is the charge of an electron, and  $V_0$  is the turn-on voltage of the LED. In terms of the wavelength  $\lambda$ , and the Plank's constant  $h$ , we have  $c = eV_0\lambda/h$ . With some algebra we can solve this equation for  $h$ , and then determine Plank's constant by plugging in the values for the charge  $e$  and speed of light  $c$ .

As shown in Fig. 12, the experimental setup consists of a circuit with a 6V DC source, a capacitor ( $C = 0.25F$ ), a current limiting resistor ( $R = 100\Omega$ ) and several LEDs that emit a variety of visible wavelengths. After the capacitor is fully charged by the DC source, the switch is moved from position A to position B to begin the discharge of the first LED (labeled a). The voltage across the capacitor is recorded with a voltage probe attached to Vernier’s LabPro interface connected to a computer running Logger Pro. Then the same procedure is repeated for other LEDs labeled b, c, d and e. We collected data for 5mm blue, green, yellow, red and infrared (IR) LEDs (from Radio Shack) with nominal emission wavelengths of 430nm, 565nm, 585nm, 660nm and 940nm, respectively. If an additional voltage probe is used to record the voltage drop across the resistor, Kirchhoff’s laws enable us to compute the LED voltage and also the current.

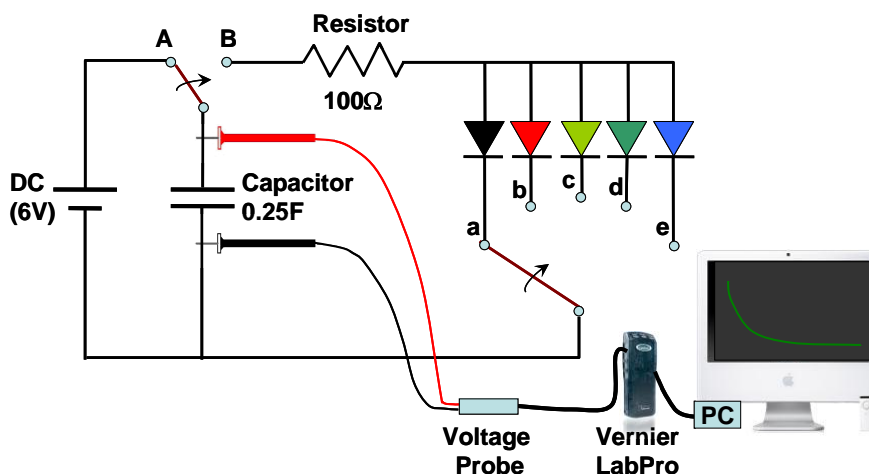


Figure 12 Experimental setup.

For the circuit shown in Figure 12, the voltage and current relationship of the diode is nonlinear, given by Shockley diode equation [8],  $i = I_0(\exp \frac{V_{LED}}{\eta V_T} - 1)$ , where  $I_0$  is the saturation current of the diode which is proportional to the diode area and materials;  $e = 1.602 \times 10^{-19}$  C, is the electron charge;  $T$  is the temperature of the p-n junction in degrees Kelvin;  $k = 1.380 \times 10^{-23}$  J/K and is Boltzmann’s constant, and  $\eta$  is the quality factor or sometimes emission coefficient that varies from 1 to 2 depending on the fabrication process and semiconductor materials. Often  $kT/e$  is written as  $V_T$ , known as the thermal voltage that is approximately equal to 25.85 mV at 300 K room temperature. The numerical simulation result is shown in Figure 13 with an initial condition  $i(0) = 0.045$  A when  $t = 0$ . The solid line is the simulation result and the dotted line is the fitted curve with exponential decay.

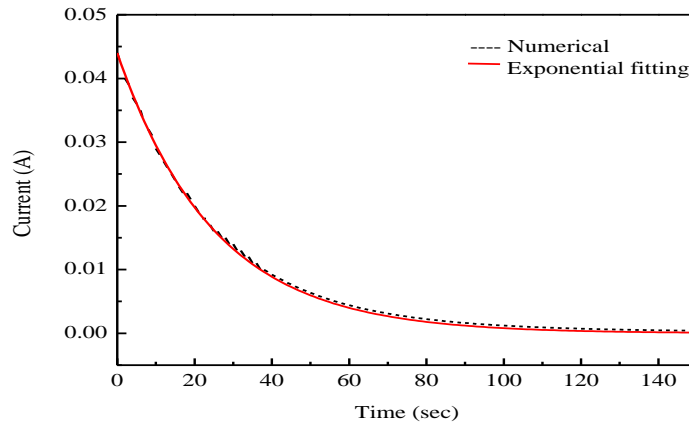


Fig. 13 Discharge current  $i(t)$  as a function of time  $t$ . The dotted line is the numerical result and the solid line is the curve fitted with an exponential function.

Fig. 14 shows typical discharge curves with the IR LED used in the circuit when two voltage probes were used. Although only the capacitor voltage is required to implement our technique, the other voltages are included here for clarity. The voltage across the resistor approaches zero and is proportional to the current in the circuit while the capacitor voltage decays exponentially from its initial maximum toward a lower limit. As a result, the voltage variation through the LED is minimized and its minimum voltage remains once there is no current flow in the circuit. An exponential decay function of the form  $V = Ae^{-Ct} + B$  fits the capacitor voltage discharge curves well, while  $A$ ,  $B$  and  $C$  are constants. The value of Plank's constant obtained from the graph shown in Figure 15 is  $6.625 \times 10^{-34}$  J-s.

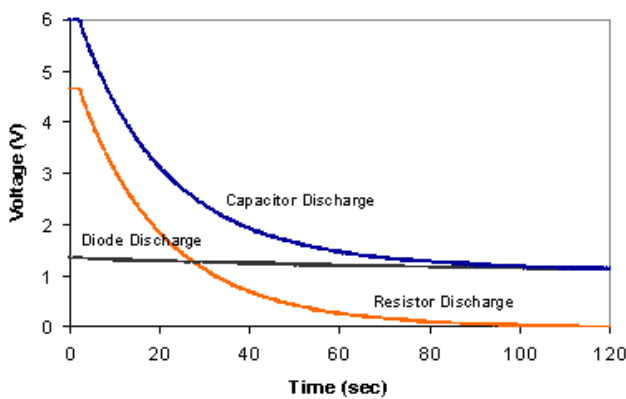


Fig.14 Typical voltage discharge curves for the IR LED.

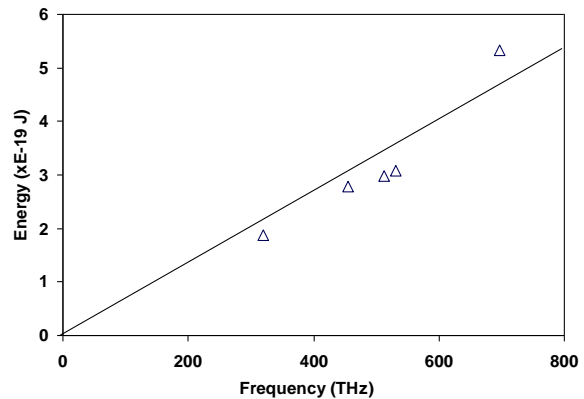


Fig. 15 Graph of frequency versus photon energy for the five LEDs.

We have shown that by measuring the discharge voltage of the capacitor in the LED circuit, we can accurately determine the threshold voltage to turn-on the LED by fitting the exponential decay curve. This method is reliable and consistent; generating a more accurate value than other reported methods using LEDs.

## Conclusions

An effective “high school pipeline” is essential to create career pathways that maintain and increase enrollment for a photonics education and workforce training program. The process and the outreach activities we have described have evolved since the program at IUP was launched in 2002. It provides to high school students hands-on lab experiences with exposure to emerging technologies in solid state lighting and solar photovoltaic, which demonstrates the interesting, rewarding career opportunities available in photonics. The steady growth in student participation is evidence of student interest, industrial support and a long-term commitment from faculty members and administrators. Ultimately, the benefit of the outreach is growth in program enrollment and incoming students who are focused on pursuing a career in this field, and who are better prepared to be successful in their educational experiences.

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If you have questions or require additional information, refer to the OP-TEC website [www.op-tec.org](http://www.op-tec.org) or contact us. We are available and eager to assist you in planning and enhancing educational opportunities for photonics technicians.

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