Phantastic Photon and LEDs

<u>Answers to Questions</u>:

<u>Phantastic Photons</u>

A. Glow-in-the-right color

Note #1: the LEDs are <u>not</u> monochromatic; the listed wavelengths are the peaks of the intensity spectrums provided by the manufacturer.

Note #2: Although not the point of this lab, it is worth pointing out to students that we are using the first order antinodes, but higher orders are clearly visible.

LED color	Tape glows? (YES or NO)	LED wavelength (nm)
blue	*yes*	*472*
red	*no*	*660*
green	*yes (slightly)*	*525*
orange	*no*	*620*
infrared	*no*	*875*
violet	*yes*	*430*
yellow	*no*	*590*
ultraviolet	*yes*	*395*

B. Exploring the Wavelengths of Colors

1. What do you notice about the wavelengths of the LEDs that make the tape glow? *The wavelengths that make the tape glow are all relatively short, approximately 530 nm and shorter.*

2. Light is a form of energy. Which wavelengths do you think contain the most energy? Explain. *The shorter wavelengths must contain more energy because they caused the tape to glow brighter.*

3. Notice that the tape always glows the same color no matter what color activates it. Write the color that it glows *green or yellow-green*

4. Estimate the wavelength of light emitted by the tape _*~550 nm*

5. How does the *wavelength* of the light emitted by the glowing tape compare with the *wavelength* of the LED light used to activate the tape? *The wavelength of the light emitted by the tape is longer than all of the wavelengths that activated the tape*

6. Why do you think some of the colors of light did not activate the tape? *Some of the wavelengths were too long to activate the tape.*

C. This is intense!

Distance	Blue LED	Yellow LED	Red LED	Ultraviolet LED
0.01 m	*yes*	*no*	*no*	*yes*
0.10 m	*yes*	*no*	*no*	*yes*
1.0 m	*yes*	*no*	*no*	*yes*

7. Does the intensity of the LED light make a difference in *how brightly* the tape glows? Describe your results. *Yes. For colors that activated the tape, the greater the intensity of the LED light, the brighter the tape glowed.*

8. Does the intensity of the LED light make a difference in *whether* the tape glows or not? Describe your results. *No. Even low intensity light of the right color can make the tape glow.*

9. Do you think the tape would glow if it received only a single particle of light from the ultraviolet LED? *Yes, but not visible to the human eye. If a single photon activates a single molecule, that molecule could emit a single visible photon.*

D. Look at What Popped Out!

10. Predict the color of light that will be emitted from the yellow fluorescent paint for each LED. Write your predictions in the table below. Then test your predictions using the LEDs and the spectrometer to analyze the color from the paint. Record your results below.

LED color	Predicted color of light from yellow paint	Observed color of light from yellow paint
Red	--	red
Orange	*orange*	*orange*
Yellow	*yellow*	*yellow*
Green	*yellow*	*yellow*
Blue	*yellow*	*yellow*
Violet	*yellow*	*yellow*
Ultraviolet	--	yellow

11. Why does the ultraviolet light get converted to yellow light by the yellow fluorescent paint, but the red light remains red? *The ultraviolet light has enough energy to activate the fluorescent paint and make it emit yellow light. The red light does not have enough energy and simply gets reflected.*

12. White light is composed of all colors of light. Explain why white light makes yellow fluorescent paint look so intensely yellow. *All wavelengths of light shorter than yellow get converted to yellow light. Therefore, the yellow fluorescent paint can emit more intense yellow light than originally present in the incident light.*

13. Predict the color of light that will be emitted from the *different* fluorescent paints for a *green* LED. Write your predictions in the table below. Then test your predictions using the *green* LED and the spectrometer to analyze the color from the paint. Record your results below.

Paint color	Predicted color of light from paint	Observed color of light from paint
Red	*red*	*red*
Orange	*orange*	*orange*
Yellow	*yellow*	*yellow*
Green	*green*	*green*
Blue	*green*	*green*

14. Explain your observations from the table above. *Each fluorescent paint emits light of its own color, provided the incident light has great enough energy to activate the paint. Green has enough energy to activate red, orange and yellow paints. It does not have enough energy to activate green or blue paint, so the green light is simply reflected.*

E. Quantum Dots

15. What colors of light did each of the four quantum dot samples emit?

- *This will depend on the samples provided in your kit.*
- *Solid samples: red-orange, orange, yellow, lime green, aqua blue (blue quantum dots are difficult and costly to produce, and hence are not very common.)*
- *Liquid samples: red-orange, orange, yellow, lime green*

16. Which quantum dots have the largest diameter? Which have the smallest? Why? *The color of a quantum dot depends on its diameter. Larger quantum dots emit lower energy (longer wavelength) light. The largest quantum dots in our sets will emit red-orange light and the smallest quantum dots will emit aqua blue light (smallest diameter, smallest wavelength, largest energy.)*

17. Predict which quantum dots will be excited by each LED color and write your predictions in the table below. Then test your predictions and record the results.

	PREDICTIONS **List the quantum dots you expect will be excited by each LED**	**OBSERVATIONS** **List the quantum dots that are actually excited by each LED**
Red		*None*
Orange		*None*
Yellow		*red-orange, orange*
Green		*Red-orange, orange, yellow* *Green (liquid only)*
Blue		*Red-orange, orange, yellow* *Green (liquid only)*
Violet		*Red-orange, orange, yellow* *Green (liquid and solid)*
Ultraviolet		*All*

18. Why can't the red LED excite the green quantum dots? *The light photons exciting the quantum dots must have at least as much energy as the light photons the quantum dots will emit. A red LED can't excite a green quantum dot because its photons don't have enough energy to do so.*

19. What determines whether a particular quantum dot will be excited by a particular LED?
A particular LED will excite a particular quantum dot if the LED's photon energies are greater than or equal to the necessary energy (corresponding to the quantum dot color).

F. Post-lab Questions

20. Complete the chart below by calculating the energy of a ***single photon*** of light for each of the LEDs in your set. Remember that the frequency of light f is related to its wavelength λ through the formula $f = c/\lambda$ where c is 3.0 x 10^8 m/s.

LED color	Wavelength (nm)	Wavelength (m)	Frequency (Hz)	Photon energy (J)
infrared	*875*	*$8.8x10^{-7}$*	*$3.4x10^{14}$*	*$2.2x10^{-19}$*
red	*660*	*$6.6x10^{-7}$*	*$4.5x10^{14}$*	*$3.0x10^{-19}$*
orange	*620*	*$6.2x10^{-7}$*	*$4.8x10^{14}$*	*$3.2x10^{-19}$*
yellow	*590*	*$5.9x10^{-7}$*	*$5.1x10^{14}$*	*$3.4x10^{-19}$*
green	*525*	*$5.3x10^{-7}$*	*$5.7x10^{14}$*	*$3.8x10^{-19}$*
blue	*472*	*$4.7x10^{-7}$*	*$6.4x10^{14}$*	*$4.2x10^{-19}$*
violet	*430*	*$4.3x10^{-7}$*	*$7.0x10^{14}$*	*$4.6x10^{-19}$*
ultraviolet	*395*	*$4.0x10^{-7}$*	*$7.4x10^{14}$*	*$4.9x10^{-19}$*

21. As wavelength increases, what happens to the energy of a photon? *The energy of a photon decreases as wavelength increases.*
22. An the number of photons increases, what happens to the total energy of the light? *The total energy of the light increases with the number of photons.*
23. The red LEDs used here convert most of their ~0.03W of power into light. (1 W = 1 J/s) Estimate the number of photons per second produced by the red LED.

$$0.03\frac{\text{J}}{\text{s}} * \frac{1\,\text{photon}}{3.0\times10^{-19}\ \text{J}} = 1\times10^{17}\ \frac{\text{photons}}{\text{s}}$$

24. Use the concept of photons to explain why red light, even if it is intense, cannot make the glow-in-the-dark tape glow (emit light). *Intense red light is composed of many red photons, each with energy $3.0x10^{-19}$ J. Photons can only get absorbed one at a time, and each red photon does not have enough energy to activate the tape, which requires ~$3.5x10^{-19}$ J, the color of yellow-green light.*
25. When the glow-in-the-dark tape absorbs blue photons, it emits lower energy yellow-green photons. If energy is always conserved, explain how the energy emitted can be less than the energy absorbed. *The extra energy is deposited in the glow-in-the-dark tape as heat, or increased kinetic energy of atoms and molecules.*
26. Use the concept of photons to explain why a yellow fluorescent highlighter appears much brighter than a regular yellow marker in normal lighting conditions. *Regular yellow marker ink reflects the ambient yellow light from the white room lights and*

that is all. The ink from a yellow fluorescent highlighter does that as well, and in addition it absorbs higher energy photons and reemits some of their energy as photons of the same bright yellow color as the reflected light. The result is brighter yellow light, overall.

27. Some clubs use black lights (ultraviolet lights) for a special effect to make white clothing glow. Explain how this works. *Clothes are typically washed with detergents which contain 'whiteners', and these materials are chosen because they are fluorescent. Although they work on all clothes, their effect is most noticeable with white clothes. The U.V. light ('black lights' emit both violet light which is visible to the human eye and 'near ultraviolet light' which is not) excites molecules in the brightener which then emit some of that energy as photons in the lower energy of the visible spectrum. Since most of the light starts outside of the visible spectrum and ends up in the visible spectrum, it makes the clothes seem to glow. In a very real sense, they do!*

28. Photoresist, a chemical used in making computer chips, changes its solubility when exposed to ultraviolet light. Why are cleanrooms where photoresist is used illuminated with yellow light? *The yellow light does not have as much energy as ultraviolet light and will not expose the photoresist unintentionally. Also the human eye is most sensitive to yellow to green light, so it still allows workers to see well.*

29. A silicon photodiode used as a light detector can only absorb photons of energy greater than 1.1 eV. Will it absorb photons from the infrared LED? *Converting the threshold energy to Joules gives* $1.1\,\text{eV} * \frac{1.6\times10^{-19}\ \text{Joule}}{1\,\text{eV}} = 1.8\times10^{-19}\ \text{J}$

As calculated in question 1, the energy of a photon from the infrared LED is 2.2×10^{-19} *J, which is above the threshold. Therefore, the silicon photodiode will absorb the photon from the infrared LED.*

LEDs

A. **Prelab**

1. What is the relationship between electric potential and electric potential energy? *Electric potential multiplied by charge equals electric potential energy. $E = qV$.*

2. How much electric potential energy does each electron lose when passing through the resistor? $E = qV = (1.6x10^{-19}\ C)(5\ V) = 8x10^{-19}\ J$

3. What is the relationship between f and λ? *Frequency equals speed of light divided by wavelength. $f = c/\lambda$.*

4. What is the relationship between the energy of a photon (E) and frequency of its light (f)? *Energy of a photon equals Planck's constant multiplied by frequency. $E = hf$.*

5. Calculate the energy of a photon of wavelength 500 nm. (1nm = 10^{-9}m)

   $f = c/\lambda = (3.0x10^{8}\ m/s)/(500x10^{-9}\ m) = 6.0x10^{14}\ Hz$

   $E = hf = (6.6x10^{-34}\ Js)\ (6.0x10^{14}\ Hz) = 4.0x10^{-19}\ J$

6. If electrons flowing in a circuit were to lose an amount of energy equal to the photon energy found in the last question, what would be their change in voltage?

   $V = E/q = (4.0x10^{-19}\ J)/\ (1.6x10^{-19}\ C) = 2.5\ V$

B. **Making LEDs Light Up**

7. Try hooking up the positive and negative leads both ways to the LED. Does it matter which way you hook them up? *Yes, the LED will not light if the polarity of the leads is not correct.*

8. What is the voltage across the red LED when it is lit? *The voltage across the red LED is about 1.8 V.*

9. What is the voltage across the blue LED when it is is lit? The voltage across the blue LED is about 3.6 V.

10. Based on your voltage measurements, do electrons in the red LED or the blue LED lose the most energy? *The greater voltage drop across the blue LED indicates that an electron loses the most energy in the blue LED.*

11. Which color of light contains photons of greater energy, red or blue? *Blue light contains photons of greater energy.*

12. What is the qualitative relationship between voltage drop across an LED and the color of light it emits? *The greater the voltage drop across an LED, the greater the frequency of the light it emits or the bluer the color.*

C. **LEDs in Reverse**

13. What is the maximum voltage? *About 1.4 V.*

14. What is the voltage across the red LED when the green LED is turned off? *Typical answers will be a few hundredths of a volt, depending on the amount of background light in the room and the orientation of the LED to the background light source.*

15. Explain the last two voltage measurements. *When the green light entered the red LED, electrons in the red LED absorbed the photons and gained electric potential energy, creating a voltage across the red LED. When the green LED was turned off, the only photons with sufficient energy to create a voltage where the few coming from ambient light, so the voltage dropped almost to zero.*

16. What is the voltage across the green LED with the red light shining into it? *There is no detectable voltage across the green LED when red light enters it.*

17. Explain your observations from the previous question. *The red photons do not have enough energy to get absorbed by the electrons in the green LED. (This is due to a larger band gap in the green LED. See "Background Information for Teacher.")*

18. Predict what will happen if you shine ultraviolet light into the green LED. *The ultraviolet light will have enough energy to be absorbed by electrons in the green LED, causing a voltage across it.*

19. Try the experiment from the last question and describe your results. *Answers will vary.*

D. **Measuring Planck's Constant**

The LED voltages below were measured with a 0.010 mA current through the LEDs.

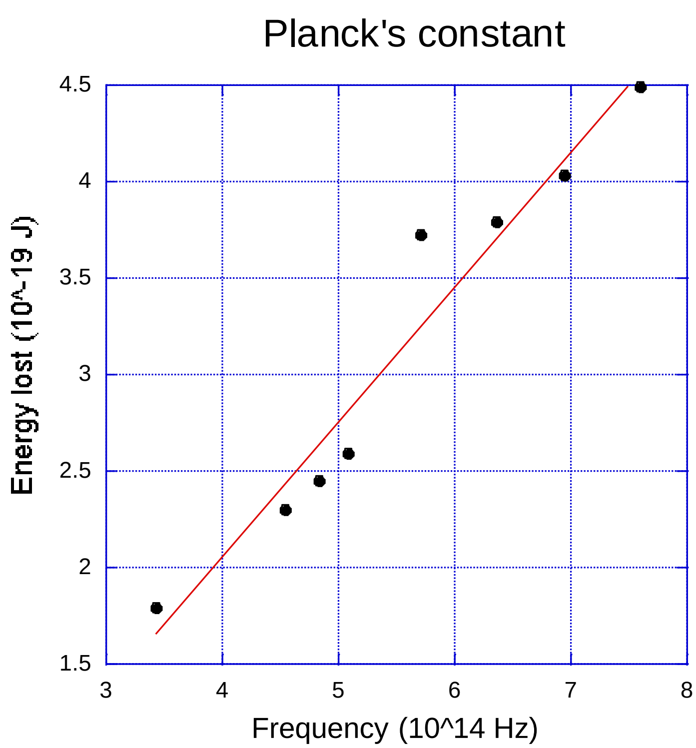
LED	Frequency (Hz)	LED voltage (V)	Energy lost (J)	Energy lost (eV)
infrared	*3.43×10^{14}*	*1.12*	*1.79×10^{-19}*	
red	*4.55×10^{14}*	*1.44*	*2.30×10^{-19}*	
orange	*4.84×10^{14}*	*1.53*	*2.45×10^{-19}*	
yellow	*5.08×10^{14}*	*1.62*	*2.59×10^{-19}*	
green	*5.71×10^{14}*	*2.33*	*3.73×10^{-19}*	
blue	*6.36×10^{14}*	*2.37*	*3.79×10^{-19}*	
violet	*6.94×10^{14}*	*2.52*	*4.03×10^{-19}*	
ultraviolet	*7.59×10^{14}*	*2.81*	*4.50×10^{-19}*	

The LED wavelengths below are at the peak intensity of the LED output spectrum provided by the manufacturer.

LED	λ (nm)	λ (m)	f (Hz)
infrared	*875*	*$8.75x10^{-7}$*	*$3.43x10^{14}$*
red	*660*	*$6.60x10^{-7}$*	*$4.55x10^{14}$*
orange	*620*	*$6.20x10^{-7}$*	*$4.84x10^{14}$*
yellow	*590*	*$5.90x10^{-7}$*	*$5.08x10^{14}$*
green	*525*	*$5.25x10^{-7}$*	*$5.71x10^{14}$*
blue	*472*	*$4.72x10^{-7}$*	*$6.36x10^{14}$*
violet	*432*	*$4.32x10^{-7}$*	*$6.94x10^{14}$*
ultraviolet	*395*	*$3.95x10^{-7}$*	*$7.59x10^{14}$*

20. Compare the voltages of the different LEDs with the frequency of the light emitted by the LED. What trend to do you observe? Explain. *The voltage across the LED increases with the frequency of the light emitted. A greater voltage means that an electron loses more energy, which allows a photon of greater energy and frequency to be created.*

Plot the energy lost by an electron versus the frequency of the light emitted for all the LEDs on a separate piece of graph paper or on a computer.



21. What does the slope of this graph represent? *The slope is an estimate of Planck's constant.*

22. Find the slope of the graph and record it here with units included. *Answers will vary within 20% of the accepted value for Planck's constant (6.6×10^{-34} Js).*

23. Why does this experimental value differ from the established value of 6.626×10^{-34} J·s?

The slope of the graph shown above is 7.0×10^{-34} Js. Note that there is some scatter in the data and not all points fall on a straight line. This is because the assumption that the energy lost by the electron equals the energy of the emitted photon is not entirely true. The interaction takes place inside of a solid state material, and other processes occur that affect the energy of the photon emitted.