

USING LEDS TO DEMONSTRATE PROPERTIES OF LIGHT AND THE INTERACTION OF LIGHT AND MATTER

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CHEMISTRY CONCEPTS

Properties of Light and the Interaction of Light and Matter

Visible light, detected by our eyes, is approximated by red, green and blue light.
Red, green and blue light have different wavelengths, and energies.
Blue light is more energetic than green light than red light.
Electrons are in quantized energy levels.
Phosphorescence has a longer observed emission than fluorescence.
Fluorescence spectroscopy is more sensitive than UV–Visible Absorption Spectroscopy.

Interaction of Energy and Matter Physical Science Content Standard B
Light waves have energy and can transfer energy when they interact with matter.
Each kind of atom or molecule can gain or lose energy only in particular discreet amounts.

Scientific Process Skills

Making qualitative observations
Constructing a model of atoms (molecules) from observed phenomena
Experimental design

HOW THE DEMONSTRATION ADDRESSES THE CONCEPTS

The demonstration makes the concepts “visible” to students. Using handheld colored LED flashlights, students see approximately monochromatic red, green and blue light. The three lights together approximate “white” light. The red LED, lowest in energy does not excite a zinc sulfide doped with copper phosphorescent vinyl sheet. The green LED causes moderate phosphorescence. Bright phosphorescence is observed with the blue LED. Since the same phosphorescent vinyl sheet is used, students directly observe blue light has the most energy of the three colors of light.

The same three colored LEDs can shine on solutions of fluorescein for a demonstration of fluorescence. Observing phosphorescence and fluorescence with the same excitation sources, helps students see the difference between the two processes. Again the blue LED causes the greatest fluorescence. The 1×10^{-5} M fluorescein solution is visibly

yellow, at this concentration; fluorescein is detectable by both UV-visible absorption spectroscopy, as a yellow solution, and fluorescence spectroscopy, as a green fluorescence with scattering. In contrast, the 1×10^{-8} M bottle of fluorescein is not visibly yellow, not detected by UV visible absorption spectroscopy, but the fluorescein present is observed visibly again by a green fluorescence with scattering. The general trend that fluorescence spectroscopy is more sensitive than UV-visible absorption spectroscopy is also observed by students.

Since the phosphorescence observed is always a yellow-green emission of light, whether excitation occurred with a green, blue or (violet) LED, student see the electron in the zinc-sulfide doped with copper only emits light from the same quantized energy levels. Students also observe the emitted light is of lower energy than the excitation light.

PREPARING AND PERFORMING THE DEMONSTRATION

Safety

Do not shine LEDs directly into student's eyes. If a violet/ultraviolet LED is used, extra caution must be taken with this LED.

Fluorescein (Disodium salt, LD 50 is 4739 mg/kg for mice) is not considered toxic. It is used to track water sources, water pollution sources and approved by the FDA in externally applied drugs and cosmetics. Solutions can be prepared, stored and reused. The demonstration does not require opening the bottles.

Equipment and Materials

LED keychain or novelty flashlights with red, green and blue lights, additional colored LEDs, orange, yellow, violet are also available and can be used as well. Seasonally or from some vendors, these can be as inexpensive as \$1.00 per light.

Zinc sulfide doped with copper phosphorescent vinyl, this is also sold as glow-in-the-dark vinyl. Glow-in-the-dark toy stars also work.

0.0033 grams fluorescein
About 50 mL alcohol
Volumetric glassware to prepare solutions
2 or 3 1 liter bottles with tight screw caps
Frozen spinach
70 % Isopropyl alcohol

Preparation of Solutions

Dissolve the 0.0033 grams of fluorescein in as small amount of alcohol as possible, dilute with water to 1L in a volumetric flask. This is a 1×10^{-5} M fluorescein solution. Pour the solution into a labeled bottle.

Measure 1.0 mL of the 1×10^{-5} M fluorescein solution into a 1L volumetric flask, dilute with water to the 1 L mark. This is a 1×10^{-8} M fluorescein solution. Pour into a labeled bottle.

(Optional solution: (for larger lecture halls) prepare 1×10^{-7} M fluorescein, by diluting 10 mL of the 1×10^{-5} M fluorescein to a volume of 1 L.)

Pour 70% isopropyl alcohol over spinach. Stir occasionally. Filter the light green solution into a labeled 1 L bottle. Dilute with additional isopropyl alcohol.

Performing the Demonstration

Begin by having the glow-in-the-dark vinyl squares turned upside down, or in an opaque folder or box. Turn on a red LED flashlight. Darken the room as much as possible. (If students are already asleep, they won't notice.)

With the tip of the LED touching the zinc sulfide doped with copper vinyl sheet move the red LED on the surface of the vinyl sheet. No glow will be observed. Repeat with the green LED and observe a detectable glow from the vinyl sheet. Students observe the brightness of the glow and how long the glow persists. Finally move the blue LED on the vinyl surface. The glow will be brighter and visible longer. If a violet LED is available, the violet LED can excite the glow-in-the-dark material as well. The glow is even brighter.

Tape a black piece of paper to the back of the bottles of fluorescein. Shine the red light on the side of the bottle and observe the transmitted beam through the bottle with a very small amount of scattering. Repeating with the green LED will give a yellow green fluorescence with scattering. The yellow-green fluorescence is greatest with the blue LED. If a violet LED is available, it can also be used to generate the observed fluorescence, however the fluorescence will not be as bright as with the blue LED.

To observe the combination of red, green, and blue light to approximate white light, it works best to hold the LEDs sideways and look at the light reflected off a piece of white paper.

Handling of Waste

The fluorescein solutions are not consumed. These solutions may be stored indefinitely. Later they may be disposed of according to local ordinances.

PEDAGOGICAL STRATEGIES FOR FOSTERING LEARNING AND UNDERSTANDING OF THE CONCEPTS

In the Chemistry in the Community or Modern Society based chemistry courses, students learn how the structure of the atom was elucidated. They view the older chemists,

Dalton, Faraday, etc as being from another world. They view more recent scientists, Einstein, Bohr, Schrodinger, etc as being geniuses. This demonstration is a way to make the energy changes induced by light in atoms and molecules concrete to students. Since students must use the model of the atom, with quantized energy levels for electrons in their explanations of the phenomena, students may understand the model of the atom better.

Students in college prep, AP Chemistry or General Chemistry use the equations: $c = \nu\lambda$, and $E = h\nu$ to further understand light wavelengths and energies, and quantized energy levels. For some students, these equations remain memorized facts that can be combined to generate correct answers. A demonstration that allows students to “see” the difference in energy of different wavelengths of light may help students understand the phenomena, and relevant equations.

In phosphorescence, the emission is observable for some time after the excitation source is turned off, so it can immediately capture student attention. First touch the red LED, a small but bright red light, on the glow-in-the-dark vinyl. Students will observe that no visible trail is observed on the plastic sheet as the light is moved. (Depending on one’s tract record as a demonstrator, one might make a comment about another demonstration seeming to fail.) Switch to a green LED, and observe that a moderate yellow green glow is observed. Finally switch to a blue LED, and observe a much brighter and longer lasting yellow green glow. (In a class with students responsible for the equations $c = \nu\lambda$, and $E = h\nu$, one might have different groups of students calculate the energies of the following wavelengths of light prior to the demonstration. The wavelengths of light from some colored LEDs are: red, 630 nm; orange, 605 nm; yellow, 592 nm; green, 525 nm; blue, 470 nm; and violet, 405 nm. The observed yellow green emission of the zinc sulfide doped with copper pigment occurs at 520 nm.) The absorption maximum for the zinc sulfide doped with copper is 365 nm, so a violet LED, or ultraviolet LED causes the brightest emission from the glow-in-the-dark vinyl.

Some questions to ask the students follow:

The first and most obvious question is what is different about the three LEDs. *Since the same vinyl glow-in the-dark square was used, and the emission increased as the LEDs changed from red to green to blue, the energy of the light emitted increases as the LEDs change. Blue light has more energy than green light which has more energy than red light. Some LED flashlights are in transparent plastic cases which allow students to see the diodes of all three colored LEDs are similar sizes and the batteries appear approximately similar in size as well.*

Why is emission of light not observed using the red LED as the excitation source? *The red light is lower in energy than the energy of the yellow green emission observed from the glow-in-the-dark vinyl. Insufficient energy was supplied to the electron therefore it was not excited to the higher energy level of the observed emission.*

Why is the emission of energy stronger and longer lasting but still yellow green when the blue LED is used as an excitation source? *The blue LED (or violet LED if available) has higher energy which excites more of the electrons in the glow-in-dark vinyl to the higher energy state. Since more electrons are excited, the glow is observed for a longer time as well. (The maximum absorption of Cu doped ZnS occurs at 365 nm, so the green to blue to violet change is increasing absorption by the Cu doped ZnS.) In excitation, the higher energy blue or violet light only provides more energy for more of the same quantized transitions to occur. (The transition is from an atom with all electrons with low energies to one with one electron in a higher energy state and all other electrons with low energies.) For emission the yellow green glow is observed with light emitted from the state with one electron in a higher state to the state with all electrons at low energies. Since the energy change from the higher state to the lower state is the same (quantized), the same colored emission is observed even if the excitation sources are different.*

Why does the emission of light occur with the glow-in-the-dark vinyl? *Students do need to consider that the phosphorescence observed is a special effect. Usually materials release energy absorbed of all three different colored LEDs by thermal or increased translation, vibration, rotation or other non-radiation processes.*

How is phosphorescence different from fluorescence? *If phosphorescence is to be compared to fluorescence, it may be useful to discuss with students what causes the delayed emission of energy in phosphorescence.*

Both phosphorescence and fluorescence involve the light induced excitation of an electron of the lowest energy state to an initial excited state. In fluorescence the initial excited state very, very quickly converts to the lowest energy state with emission of light energy.

In phosphorescence, conversion of the initial excited state, called a singlet state to a lower energy excited state, called a triplet state occurs with a change in spin of the electron. Since the triplet state to ground state conversion involves a change in spin of the electron as well as emission of light energy, the lower energy excited state is longer lived, and the emission is observed after the excitation sources is removed.

In the demonstration of fluorescence, the red, green and blue LEDs are observed through a solution of 1×10^{-5} M Fluorescein. A small amount of scattered red light is observed as the red LED shines through the fluorescein solution. Switching to a green LED causes a yellow green emission of light to be observed. Finally, the blue LED causes the brightest yellow green emission. Unlike phosphorescence observed previously, the fluorescence emission from fluorescein occurs very, very rapidly. It appears the emission occurs, only while the sample is being excited.

With a violet LED, it is possible to notice that the yellow green fluorescence emission is decreased from that observed with the blue LED. This may puzzle students initially, because more light with more energy caused greater emission in the zinc sulfide doped with copper phosphorescence. However, the maximum absorption of fluorescein occurs

at 496 nm, which is closest to the emission wavelength of the blue LED of 470 nm. The process of shining different colored LEDs through the fluorescein solution, red, 630 nm; orange, 605 nm; yellow, 592 nm; green, 525 nm; blue, 470 nm; and violet, 405 nm, is reminiscent of scanning spectroscopy. The observed fluorescence emission is greatest at the wavelength of maximum absorption. It is just by coincidence that the wavelength of the emitted light for fluorescence of fluorescein is also 520 nm.

The fluorescence of quinine in tonic water might be observed with a violet LED, or the fluorescence of chlorophyll from spinach in isopropyl alcohol can also be observed with a violet LED. A pale solution of chlorophyll extracted from frozen spinach into isopropyl alcohol works best. (Different chlorophyll compounds absorb at slightly different wavelengths, but 350 nm is one average absorption maxima, the wavelength of light emitted from chlorophyll is about 670 nm. These additional fluorescence examples illustrate that the light emitted is not always yellow green.

Garrity Fun-Tastick, battery operated LED glow stick lights can be combined and the emitted light observed on a white background to observe the addition of different colors of light. Red and green light produce a yellowish light, while red, green and blue produce a version of white light. These LEDs are better for younger children to use, the LED is not too small and the on-off switch is sturdy. These larger, sturdy LEDs make this demonstration of properties of light and the interaction of light and matter a very accessible chemistry outreach activity.

A demonstration of the protection from ultraviolet radiation provided by clothing, sunglasses, or sunscreen can also be done using these protective items, the Cu doped ZnS phosphorescent vinyl sheet, and the blue (or preferably a violet LED.) The sunglasses or other sun protection to be evaluated is placed on top of the glow-in-the-dark sheet and the blue (or violet) LED light shines on top of the sunglasses. After turning off the LED and removing the sunglasses, or other sun protection, any darkened (not excited by the light) area on the glow-in-the-dark vinyl displays the UV protection.

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