Lesson Plan: Let It Glow!

FOR THE TEACHER

Summary
In this lesson students will investigate the fluorescence of a variety of everyday items as well as prepared samples under a black light. Students will examine the concepts of absorption and subsequent emission of photons, as well as wavelength, frequency, and energy of electromagnetic radiation. As extension activities, students will learn about phosphorescence and research real-life applications of photoluminescence.

Grade Level
High and Middle School

NGSS Alignment
This lesson will help prepare your students to meet the performance expectations in the following standards:

- **HS-PS2-6**: Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.
- **HS-PS4-3**: Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other.
- **HS-PS4-4**: Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter.
- **Scientific and Engineering Practices**:
  - Using Mathematics and Computational Thinking
  - Analyzing and Interpreting Data

Objectives
By the end of this lesson, students should be able to

- Identify a number of everyday items that will fluoresce under a black light.
- Explain the emission/absorption of photons of light.
- Describe what is happening to the electrons in atoms/molecules when fluorescence occurs.
- Differentiate between fluorescent objects and glow-in-the-dark objects using the terms fluorescence and phosphorescence.

Chemistry Topics
This lesson supports students’ understanding of

- Energy
- Electromagnetic radiation
- Frequency
- Wavelength
- Electrons
- Quantitative Chemistry
- Photon emission
- Photon absorption
- Fluorescence

Time
**Teacher Preparation**: 60-180 minutes
**Lesson**: 
- Engage: 10-30 minutes
- Explore: 45-100 minutes
- Explain: 30-60 minutes
- Elaborate: 20-40 minutes (Optional extension activities: additional 20-120 minutes)
- Evaluate: 30-60 minutes

**Materials**

- Black light(s) (UV-A light bulb)
- Everyday items (teacher examples and items from students)
  - Lego bricks
  - White t-shirts
  - Cotton balls
  - Highlighters
  - The website [Science Notes](#) has a great list of everyday items that fluoresce visibly under a black light.
- Grocery store/pharmacy items:
  - Fluorescent paint
  - Antifreeze
  - Laundry detergent
  - Mr. Clean liquid cleaner
  - Irish Spring soap
  - Vaseline petroleum jelly
  - B12 vitamins
  - Alka-Seltzer
  - Tonic water (with quinine)

- Other Item Suggestions:
  - Different denominations of money (see photo)
  - Passports
  - Driver’s license
  - Credit cards
  - Note: UV lights will show a different color security band for different denominations of bills. Reference [this link](#) for colors of bands.

For each lab group:

- 2 sets of note cards or white paper
- 1 yellow (or pink) marker (Crayola suggested)
- 1 yellow (or pink) highlighter marker (Office Depot brand highlighters seem to have the brightest intensity under the black light)
- 1 set of highlighters (3-4 different colors)
- A set of white objects such as:
  - Wood painted white
  - White cotton ball
  - Sample of white leather
  - Sample of white plastic
  - White metal
Safety

- Students should wear goggles.
- Students should not look directly at the black light bulb for a long duration of time.
- Teachers should use a black light bulb with rays in the UV-A portion of the spectrum and not simply a UV lamp, as UV bulbs with shorter wavelengths and higher energy (UV-B or UV-C) can be damaging to the eyes.
- Check safety, warning, and disposal labels on any grocery item, especially items like cleaners, vitamins, and antifreeze.

Teacher Notes

- **Preparation:** If you have only one black light, you will need to conduct this activity as a demo and perhaps complete only some of the Parts I-V. It is best if you can set up your light in a completely dark room. You can purchase black light keychains if you would like to set up more stations for students but cannot afford to purchase multiple full-sized lights.

- Even if you have multiple lights, you may want to set up Part I as a teacher demo and introduction. Then allow students to work in groups for Parts II-V. If you only have a few black lights, you could allow students to rotate through stations, if you have a space where other students could work in light. If you have only one light, you could arrange Parts II-V of this lab to take place while other students are working on independent classwork and perhaps have one group at a time rotate into a dark closet, where you can monitor at the door. If time constraints or material constraints are an issue, this lab is still effective with only Parts I, III, and IV.

- For Part I, prepare samples that you would like to share with your classes. Check with other teachers at your school to see if they might have rock samples, fluorescent dyes, scorpions, or other interesting items that fluoresce. Make a grocery run to pick up some everyday items to test. See Materials section for suggestions. Science Notes website also has a great list of items.

- For Part II, ask each student or team of students to bring an object from home to test for fluorescence. Approve all student items before allowing groups to begin testing in Part II; students may attempt to bring inappropriate glow-in-the-dark items such as condoms, so make sure to allow sufficient time for students to get their items approved.

- For Parts III and IV, obtain white paper strips or index cards. For Part III, a yellow marker and yellow highlighter are needed for each group. (You can compare an orange or pink marker to its same colored highlighter, as long as desired effect of non-glowing marker ink and glowing highlighter ink is achieved with your sets.) During the lab, you will ask students to write a word on white index cards (or white paper) using yellow marker versus yellow highlighter. I wrote “yellow marker” and “yellow highlighter,” which is not overly original but it helped me remember which sample was which. For Part IV, prepare more white paper strips or index cards and a set of colored highlighters (3-4 different colors) for each group. During the lab in Parts III and IV, students will observe which marker and highlighter colors “glow” under the black light and which colors don’t.

- Make sure to check your examples and chosen yellow marker, highlighters, etc. under the black light. Some highlighters will glow faintly under the black light and others do not glow at all. You may also find that some markers will also glow (like Crayola’s pink in some packages). Usually the blue highlighter does not glow so you can make the designation that not all highlighters are created equally. If you want to differentiate, give each group different brands of highlighters, with colors that glow in some brands and do not in others; then ask them to compare data. In order to make the distinction between yellow marker ink and yellow highlighter ink, I have found that Office Depot brand highlighters have the brightest highlighter ink with the most glow. I use Crayola markers as my regular marker brand.
Part III can be used to compare pink colors instead of yellow with older Original Crayola pink
markers and pink highlighters. Newer Color Max additives to Crayola markers have included
some fluorescent dye components because the ink of newer pink Crayola markers fluoresces
where older pink marker ink appears darker in visible light and does not fluoresce.

For Part IV, I have found that blue and purple highlighters do not tend to glow and yellow
highlighters always glow; fluorescence under a black light varies by brand for orange, green, and
pink. From my experience and recent purchases, the Office Depot brand highlighters have the
most intense glow under the black light; pink, orange, yellow, and green glow, but blue and
purple do not glow. Bic Brite Liner highlighters glow in pink, orange and yellow, but not in green
or blue. Sharpie highlighters glow in yellow, and green, but not in pink, orange, blue, or purple.

For Part V, obtain and prepare samples of small, similarly-sized squares of different white
objects: cotton cloth, white trash bag, white metal, etc. The goal here is to find some white
samples that fluoresce and others that do not. You may want to conclude the lab portion of this
activity with this part as a demo if you do not have enough samples for each group.

Engage: Students are interested in black lights and “glowing” objects, so in my experience it
has been easy to connect them with this topic. My school has a black-light pep rally around
Halloween each year, so I would begin a classroom discussion by referencing this much-
anticipated event.

Give out Introduction and Pre-Lab portions of the lab for students to read and then begin the
Engage discussion above or you can send these portions home with students to complete for
homework after the discussion.

I suggest introducing this lesson at the close of class and ending the Engage portion by asking
students to each bring in one item to the next class that they want to test with a black light. I
offer a prize to the most original item to encourage and inspire creativity! It’s also important to
make sure students understand that their items must be school-appropriate and that the teacher
must sign off on them before they can be tested.

You may want to use Flinn Fluroescent Dyes Demo (free to use and download) as an optional
Engage demonstration at this point. I recommend using this activity as a more involved way to
introduce this lesson, before starting the Procedure section, or before the Analysis portion of the
lab.

Explore: This section covers the Procedure and Observation portions of the student lab
handout. This investigation can be split into two days/class periods, where each day is
introduced by showing students something new about fluorescence, such as the glowing strips in
different bill denominations or other cool untested samples, like a scorpion or fluorescent
minerals. Refer to the Procedure section of the student document for the specific layout.

Explain: Students will complete the Calculations section, and use Background information
provided, as well as information from The Chemistry of Highlighter Colors, from Compound
Chemistry to complete the Analysis questions. Teachers may want to provide hard copies of the
Compound Interest handout, or make the link easily accessible for students.

Elaborate: Students will read the article “Let it Shine” about PPG’s glow-in-the-dark tools and
complete the questions in the Extension portion of the lab, discuss possible extensions and real-
life applications with the class. Teachers may want to provide hard copies of the article, or make
the link easily accessible for students.
• For your reference, this website summarizes some of the major differences between fluorescence and phosphorescence. It mentions forbidden spin state transitions, so it may be a bit beyond the understanding of students.

• Optional Extension Activities:
  • Flinn Fluorescent Dyes Demo (free to use and download)
    o I recommend using this demonstrations as an additional portion of the Engage section of this lesson if time allows. The activity involves observations under visible light and black light for aqueous solutions of fluorescein, rhodamine, and tonic water, and an ethanol solution of eosin Y.
  • Extension Activity 1
    o I recommend using this activity in the Elaborate section. Students can make fluorescent, phosphorescent bouncy balls or slime using borax and Elmer's glue from grocery store and glow in the dark powder from Educational Innovations. Instructions can be found in the AACT resource Changing a Monomer to a Polymer.
  • Extension Activity 2
    o I recommend using this after discussing glow-in-the-dark items. Students create their own fluorescent and phosphorescent creations, tying in a few concepts on polymers and crosslinking. The instructions can be found on my polymer lesson website, just add in the glow powder or paint!
  • Extension Demonstration
    o I recommend using this in the Elaborate section. The experiment is based on this Scientific American article, which is described in more detail in Teacher Notes below.

• Evaluate: Students complete the assessment questions as individuals or in lab partner groups, at teacher’s discretion. For an alternative method, on the short answer questions, teacher could have discussions with each student group instead of asking them to write out answers to be graded. Answer key is provided as a downloadable document for teacher reference.

FOR THE STUDENT

Lesson

Let It Glow

Black lights are a fun application of science and light! In this lab activity, you will get to explore black lights and learn some of the science behind why things “glow” under these lights.

Questions to consider:
• Does everything glow under the black light?
• Is it the initial color of the item that dictates whether it will glow and what color it will appear when placed under the black light?
• Are certain objects/colors more likely to glow under the lights?
• Does the composition of the sample affect whether it will glow under the black light?

Background
Electromagnetic radiation is a term used to describe all forms of light. It encompasses radio waves, microwaves, infrared radiation, visible light, ultraviolet rays, X-rays, and gamma rays. This light can behave as waves or particles.
In order to understand light, you need to know a few things about how it can be measured. For electromagnetic radiation, all waves travel through the vacuum of space at the speed of light, $3.0 \times 10^8$ m/s. Wavelength, abbreviated with the lowercase Greek letter lambda, $\lambda$, is the distance between two consecutive troughs or peaks of a wave; it is measured in a distance unit, often nanometers (1 nm = $1 \times 10^{-9}$ m). The frequency of a wave is abbreviated with lowercase Greek letter nu, $\nu$, and is defined as how many waves pass a given point per second; it is measured in the unit Hertz, which represents 1/second, or 1/s.

The relationship between the frequency and wavelength can be calculated using the equation $c=\lambda \nu$, where $c$ represents the speed of light constant, $\lambda$ represents wavelength in meters, and $\nu$ represents frequency in 1/s or Hertz. Energy can be calculated using $E=h\nu$, where $E$ is energy in Joules, $h$ is Planck’s constant ($6.626 \times 10^{-34}$ J·s), and $\nu$ is frequency in 1/s.

As energy increases, the wavelength of the radiation decreases and its frequency increases. As energy decreases, the wavelength increases and frequency decreases.

When an object absorbs the energy from electromagnetic radiation, its electrons become excited and move to a higher energy than their normal ground state; this higher energy state is called an excited state. The electrons, however, do not remain in this higher energy and will fall back down to their normal ground state. When they return to their ground state, the energy is given off in packets or particles of light called photons. If an object gives off light in this way, the phenomena is known as photoluminescence. If the emitted energy has a wavelength in the visible light range (around 400 to 750 nm), it can be seen by the human eye.

Ultraviolet light (UV) ranges from about 10 nm to 400 nm. Closest to visible light are the longer, less harmful UV rays, called UV-A; these are different than the shorter UV rays that can cause sunburn, which are UV-B, or the shortest, most dangerous UV rays, UV-C, which are blocked by our atmosphere and the ozone.

Black lights emit electromagnetic radiation mostly in the UV-A portion of the spectrum and some in the violet end of the visible spectrum, hence the purplish “glow.” When objects seem to “glow” under black lights, they are called fluorescent. Fluorescence is a type of photoluminescence and occurs when atoms absorb light energy at one wavelength and then emit energy at a different, longer wavelength of lower energy. When the photon of light energy is absorbed, an electron jumps to an excited state at a higher energy level. Some of this absorbed energy is transferred into vibrational energy and the rest (a lower energy, but longer wavelength) is given off when the electron falls back down to its ground state.

The atoms and molecules in objects that seem to glow under a black light are taking in
the UV-energy portion of the light, which human eyes cannot detect, and then emitting photons as lower-energy, longer-wavelength visible light, which human eyes can see. In fluorescence, the transition of the electrons and the emission of energy are almost instantaneous, so the objects begin glowing as soon as the black light is turned on and stop glowing as soon as the light is turned off.

Beyond the wow factor of black lights, fluorescence is an important application of light in science and can be used in many areas from forensics or engineering to the health industry.

**Pre-lab Questions**
1. The radio waves for the most popular local radio station have a frequency of 94.9 MHz. What is the wavelength for these radio waves? Remember that Mega means $1 \times 10^6$ of the unit.

2. The part of the spectrum that appears brightest to human eyes is around 560 nm, which appears yellow-green in color. This explains why tennis balls and school zone signs are made in this eye-catching color. What is the frequency for this visible light?

3. Gamma-ray flares from the Crab nebula were first detected in 1971 by astronomers. If the energy of these pulses measures 10 MeV (Megaelectron-volt), what frequency describes this radiation? $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$

4. What is the energy for an infrared photon with a wavelength of 0.15 mm?

5. If you have an item containing a fluorescent compound, describe what is happening at the atomic level when the object glows under the black light.

**Objectives**
- What does fluorescence look like under a black light?
- What items fluoresce under the black light?
- Does the color or composition of a sample affect whether it will fluoresce?
- What is happening at an atomic level when you see a “glow” for a sample under the black light?

**Materials**
- Black light(s)
- Examples from your teacher
- Approved sample item(s) for testing under the black light
- Note cards or white paper
- Yellow marker
- Yellow highlighter
- Other colors of highlighters
- White samples of different materials

**Safety**
- Do not look directly at the black light bulb for a long duration of time.
- Wear goggles.
- Follow the directions from your teacher regarding handling and disposal of any samples.
Procedure

Part I: Observe the examples provided by your teacher under the black light. For each item, make note of its identity and your observations; also write down any questions you may have in the data table provided.

Part II: After approval from your teacher, observe the items you have brought from home to test under the black light. For each item, make note of its identity and your observations; also write down any questions you may have in the data table provided.

Part III: Before testing, obtain two separate sheets of white paper or two index cards. Write the same word or draw the same picture on both cards, using yellow highlighter on one card and yellow marker on the other. Make note of the type of marker used for each sample. Observe samples under the black light; make notes of your observations and any questions you may have in the data table provided.

Part IV: Before testing, obtain additional sheet(s) of white paper or index cards. Write the same word or draw the same picture on each card, using a different color highlighter for each sample. Make note of the type of marker used for each sample. Observe samples under the black light; make notes of your observations and any questions you may have in the data table provided.

Part V: Observe the different white objects provided by your teacher under the black light. For each item, make note of its identity and your observations; also write down any questions you may have in the data table provided.

Observations

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<tr>
<th>Items Observed</th>
<th>Observations &amp; Questions</th>
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<tbody>
<tr>
<td>List each specific item observed under the heading for each Part of the lab.</td>
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<table>
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<tr>
<th>Part I: Teacher-provided samples</th>
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<tr>
<th>Part II: Approved student-provided samples</th>
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<tr>
<th>Part III: Marker vs highlighter</th>
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<th>Part IV: Different color highlighters</th>
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<tr>
<th>Part V: Different white samples</th>
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1. What did you discover when observing samples in Part I? Were you surprised by any of your observations? Which examples gave unexpected results?
2. What did you discover when observing your own samples in Part II? Were you surprised by any of your observations? Which examples gave unexpected results?

3. In Part III, what did you observe about the pink highlighter versus the pink marker? Were you surprised by your observation? Why or why not?

4. In Part IV, what did you observe about the yellow highlighter versus the blue highlighter? Were you surprised by your observation? Why or why not?

5. In Part V, what did you observe about the different white samples? Were you surprised by your observation? Why or why not?

Calculations

1. Black light transmits in the ultraviolet region of the electromagnetic spectrum from about 320. to 400. nm. Calculate the frequency range of the wavelengths of black light.

2. Calculate the energy range for black light.

Analysis

1. Based on what you learned from the introduction and your lab experience, compare and contrast what is happening to the electrons of atoms in the fluorescent compound of the yellow highlighter ink, which glowed brightly under the black light, to the electrons of atoms in the non-glowing yellow marker ink.

2. Could this same explanation be used to explain why the yellow highlighter glowed under the black light but the blue highlighter did not? Why or why not?

3. Your teacher will provide you with a Compound Interest handout: The Chemistry of Highlighter Colors that shows chemical structures for different highlighter inks. Do you think all brands of highlighter use the exact same formulation for the ink and colors? Could different brands of highlighter marker change the results of your experiment for Part IV? Why or why not?

4. All of the samples in Part V appeared white in visible light. Why did some of the white samples glow under the black light but others did not? What characteristic of the samples was more important than their observed white color in visible light?

Extension

Read the article “Let it Shine” about how Pittsburgh Paint and Glass (PPG) has created innovative glow-in-the-dark tools for the aerospace industry.

Glow-in-the-dark items and fluorescent items both exhibit photoluminescence. However, unlike fluorescent items, atoms or molecules in glow-in-the-dark material have delayed emission of radiation that does not stop upon removal of the light source. This is called phosphorescence. Glow-in-the-dark items must first be exposed to light to “charge” them and then will glow for a period of time once in the dark. The length of time that the item glows in the dark varies from a few minutes to a few hours.
1. If a tool has been inside a dark aircraft fuel tank, away from light, what was the method mentioned in the article that could easily be used to find it?

2. Based on what you have learned in this lesson, are fluorescent items the same as glow-in-the-dark items? Why or why not?

3. Can you think of other applications of glow-in-the-dark tools or objects?

4. Research an application of fluorescence and write a few sentences about what you find. Be prepared to share your findings with the rest of the class.