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Instructor Notes: Exploring Photochemistry & the Electromagnetic Spectrum Lab

Russ Blair, Chemistry Crimson Cliffs High School

Background & Purpose: This is a laboratory activity designed to help first year high school chemistry students develop a better understanding of the phenomena associated with electromagnetic wave interactions with matter using the photochromic chemistry of inexpensive UV sensitive beads. Additionally, the role of ZnO particle size in UV radiation blocking effectiveness may be explored using solutions of ZnO micro and ZnO nanoparticles for comparison. The lab consists of several parts and options to select from. Perform this lab after discussing the EM spectrum, and the relationships between energy, wavelength, and frequency.

Lab components:

Research and pre-lab questions
Part 1: UV bead lab (UV bead properties, effect of sunscreen, temperature and wavelength)
Part 2 Sunscreen fluorescent highlighter lab (effect of various sunscreen as a UV block using yellow highlighter florescence)

Objectives:

- Students will research the nature of skin damage caused by exposure to the UV rays from the sun.
- Students qualitatively evaluate the amount of UV penetration allowed by various sunscreens using UV sensitive beads.
- Students will observe the effect of temperature on reaction rate by observing UV bead color change at different temperatures.
- Students will observe the effect of wavelength on UV bead color change.
- (optional) Students evaluate the UV blocking effectiveness of ZnO sunscreen containing micro-sized ZnO vs. nano-sized ZnO.

Topics:

- Electromagnetic Spectrum; Radiation; Wavelength, frequency, energy relationships; UV bands (A, B, and C); health, biological effects of UV radiation; fluorescence; nanoparticles, color complementarity, reaction rate.

Differentiating Instruction:

- Portions of the lab may be conducted as a guided inquiry. See the Optional Guided Inquiry Extension at the end.
- Some possible extensions for differentiating instruction include more computational questions such as:
    - Calculate the energy of the UV light source given the wavelength (390 & 365 nm)
- Why do some beads change to different colors than others?
- Other extensions can include discussions about the role of photochromic reactions in the lenses found in eyewear, textiles, and smart windows.
- Other possible discussions can include physical vs. chemical changes, reaction reversibility, activation energy, reaction rate.

NGSS Alignment:

Disciplinary Core Ideas

HS-PS4-3: Electromagnetic Radiation

- 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: Electromagnetic Radiation

- Evaluate the validity and reliability of claims in published materials of the effects that different frequencies of electromagnetic radiation have when absorbed by matter

HS-PS2-6 Motion and Stability: Forces and Interactions

- Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

HS-PS1-5: Chemical Reactions

- Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

Crosscutting Concepts

1. Cause and effect
2. Energy and matter
3. Systems and system models
4. Stability and change

Science and Engineering Practices

1. Analyzing and interpreting data
2. Using mathematics and computational thinking
3. Constructing explanations

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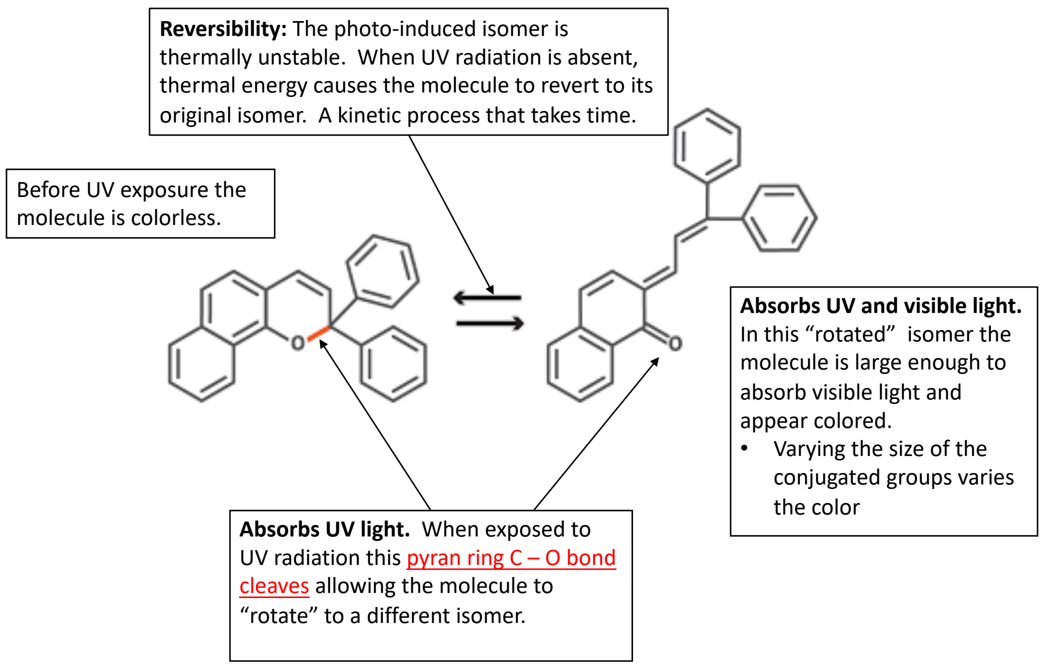
Instructor Notes for Lab Part 1 UV Bead Lab:

1. Instructors may wish to separate the UV beads by color.
2. Chemistry of UV light detecting beads (Photochromic reactions)

   a. UV light detecting beads are normally observed to be white in color before exposure to UV light. Exposing the beads to UV light causes the beads to change color. When removed from the UV light source the beads return to their original color. At the center of the naphthopyran dye molecule responsible for the color change there is a carbon atom which is bonded to two large conjugated molecules that lie at right angles (orthogonal) to each other. Conjugated groups are known to absorb light. Larger groups absorb longer wavelengths. In this orthogonal arrangement neither of the two molecules is sufficiently large enough to absorb visible light and so the dye appears colorless. When exposed to the UV light source the weak C – O pyran ring bond is broken and the previously orthogonal molecules rotate so as to be in the same plane creating a longer conjugated molecule. The larger molecule is now able to absorb certain wavelengths of visible light causing a color to appear. By adjusting the size of the orthogonal conjugated molecules, the color of the beads is changed.[1]



   Reversibility occurs because, for napthopyrans, the photo-induced isomer that results in the colored molecule is thermally unstable. In the absence of UV radiation the molecule reverts spontaneously to its original form[2].

   b. Experiment 1 in Part 1 of the lab is designed to allow students to qualitatively observe the effect of sunscreen SPF on UV radiation absorption. The UV sensitive beads absorb UV radiation at between 300-400 nm. Sunscreens with lower SPF will not absorb as much UV radiation and will thus allow a greater color change in the dye incorporated into the UV beads. Sunscreens with higher SPFs will absorb more UV radiation and cause the Beads to appear less colorful since fewer rays will cause the beads to change color.

      i. Five small test tubes are used and each filled with four or five UV beads. One of these serves as the control, the remaining four will have a different SPF sunscreen applied for comparison. The test tubes are then exposed to the 390 nm UV light source and observations recorded. Students are encouraged to use their phone cameras to help record their observations for later use. The 390 nm UV light works best. Alternatively, direct sunlight can also be used. Compared to the control students should observe progressively less colorful beads as the SPF of the sunscreen increases and should draw conclusions about why this happens.

   c. Experiment 3 in Part 1 of the lab is designed to allow students to observe several interesting effects UV wavelength has on the colors of green, blue, and yellow UV beads.

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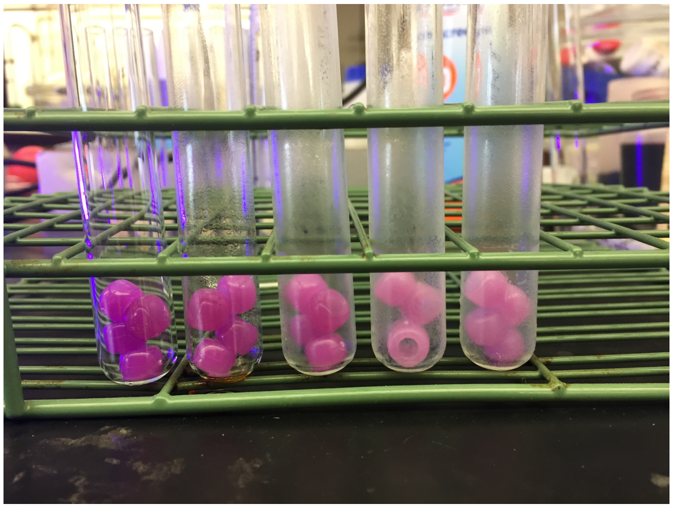
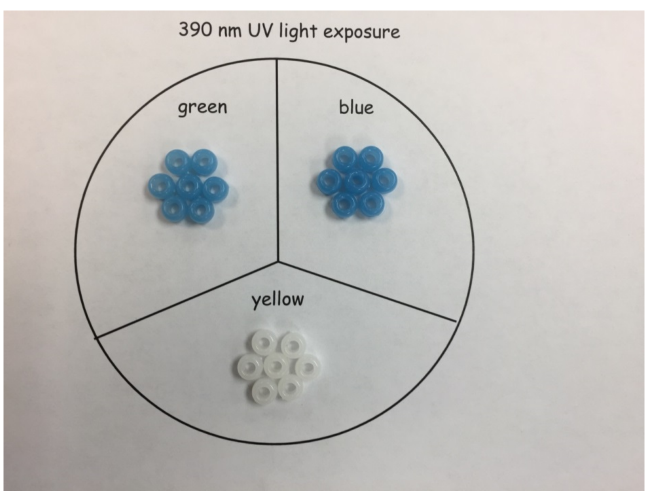
Part 1 Experiment One Examples Using a 390 nm UV light source:



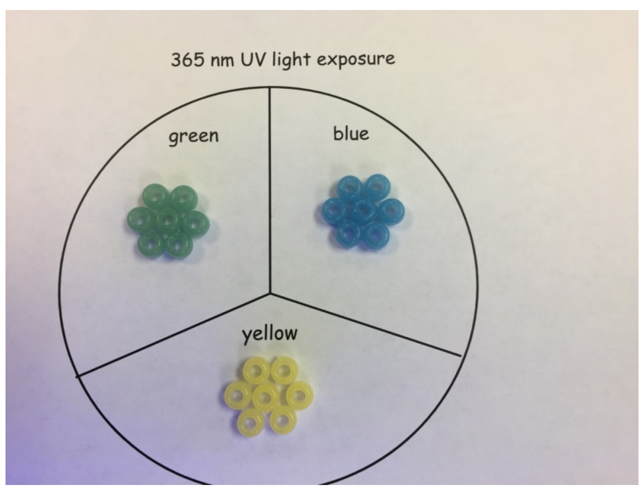
Part 1 Experiment Two Example Temperature and Rate Change Data

UV Bead Color	Time @ Room Temp (18 ℃)	Time @ heated water temp (55-57 ℃)
Blue	6:04	1:38
Red	5:03	1:30
Green	4:56	1:28
Yellow	56 sec	35 sec

Part 1 Experiment Three Examples:



390 nm UV Light



365 nm UV Light

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Instructor Notes for lab Part 2[3] Sunscreen - Highlighter Lab.

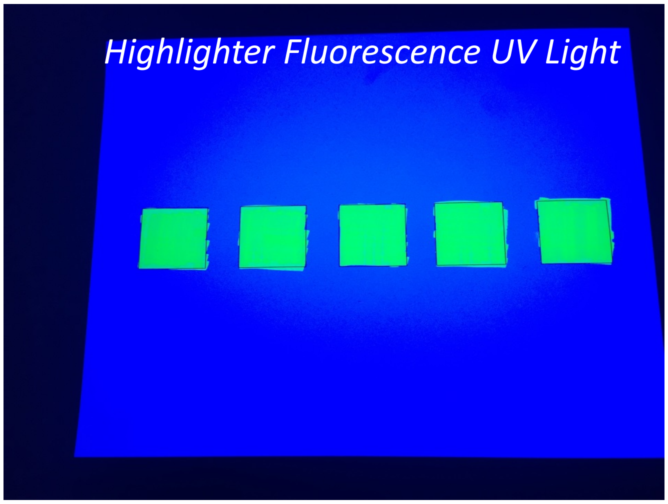
1. The experiment in Part 2 of the lab is designed alternative utilizing the phenomenon fluorescence to demonstrate the presence of UV light using the pyranine dye in yellow fluorescent highlighters. The pyranine dye in yellow florescent highlighters absorbs UV radiation at about 370 nm and emits a green light at 510 nm. Sunscreens are used to visibly demonstrate and observe qualitatively their effectiveness. Lower SPF sunscreen will not absorb as much UV radiation and will thus allow more of the pyranine dye to fluoresce. Sunscreens with higher SPFs will absorb more UV radiation and cause the highlighted area to appear darker since fewer UV rays will cause the pyranine dye to fluoresce. Additionally, the effectiveness of mineral based screens like ZnO vs. chemical based screens may be observed.

2. In part 2 fluorescence is greater when the UV light source is held closer to the surface of the paper. Instructors may wish to place the UV light source in a fixed stand 3-4 inches above the surface of the paper to help ensure consistent observations.

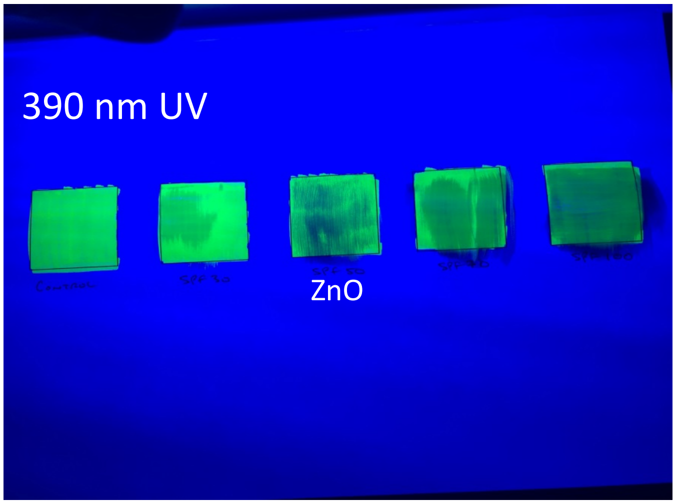
3. On a sheet of paper four squares are made and colored with the yellow fluorescent highlighter. These squares may be made in advance and printed on card stock paper. Card stock provides a better surface and minimizes wrinkling. The first square is for comparison (control). Various SPF sunscreens are applied using inexpensive cosmetic sponges. When illuminated by the 365 nm UV light the control square should have no dark area observed since no sunscreen is present. The squares covered with the sunscreens should have a varying black (darker) appearance due to absorbing some of the UV light. The square with the highest SPF should be darkest. The squares should be observed under both the 390 nm and 365 nm light.

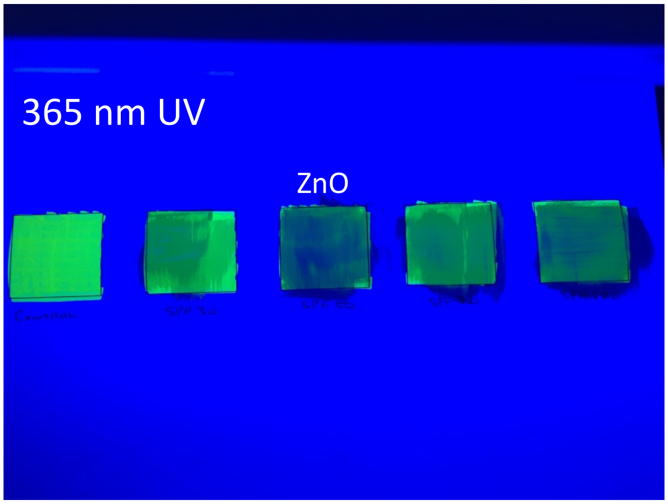
4. It is interesting to note the ZnO square color darkening change from 390 nm to 365 nm UV.

Part 3 Example of highlighter fluorescence under UV light.



Example of various sunscreens applied under 390 nm 365 nm UV light.





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Part 1 Materials Required (teacher provided):

- UV sensitive beads
- Small test tubes
- Marker
- SPF 15, 30, 50, 70, 100 spray sunscreen.
- UV light source (390 nm), UV light source (365 nm)

Part 2 Materials Required (teacher provided):

- UV light source (390 nm), UV light source (365 nm)
- Various lotion type sunscreens (SPF 30, 50, 70, 100 for example)
- At least one ZnO only sunscreen
- Wedge shaped cosmetic sponge applicators

Material Sources:

1. UV safety googles are available from Flinn Scientific
2. UV sensitive beads can be obtained from Educational Innovations.
3. Wedge shaped cosmetic applicators from Wal-Mart
4. 365 nm UV light source (available from a variety of sources)
5. 390 nm UV light source (available from a variety of sources)

Health & Safety:

UV light: The primary health concerns often associated with UV light relate to skin irritation (erythema) eye irritation (conjunctivitis). Such irritations might occur when an individual is exposed to light energy emitted under 320 nm. Lamps emitting this wavelength are within the UV-B and UV-C ranges. UV-A energy is above the 320 nm threshold. OSHA has established certain thresholds for exposure to UV light sources to ensure personnel safety:

- 150,00 hours – Continuous exposure at a distance of 20 ft from a light source.
- 1,500 hours – Continuous exposure at a distance of 6 ft from a light source.
- 40 hours – Continuous exposure at a distance of 1 ft from a light source.

References:

(1) Ron Perkins. "Ultra Violet Light Detecting Beads UV-AST a Simplified Explanation." http://cdn.teachersource.com/downloads/lesson_pdf/UV-AST-simplified.pdf Accessed 11 July 2018

(2) Sousa, Ceu M.; Berthet, Jerome; Delbaere, Stephanie; Polonia, Andre; Coelho, Paulo J., Fast Color Change with Photochromic Fused Napthopyrans. The Journal of Organic Chemistry. **2015**, 80, 12177-12181

(3) Guedens, Wanda J.; Reynders, Monique; Van den Rul, Ken Elen; Hardy, An; Van Bael, Marlies K, ZnO-Based Sunscreen: The Perfect Example To Introduce Nanoparticles in an Undergraduate or High School Chemistry Lab. *J. Chem Educ.* ***2014,*** *91,* 259-263.

(4) Katie Wirsing. "Lab: The Most Effective Sunscreen." https://www.acs.org/content/dam/AACT/middle-school/energy/radiation/lab-sunscreen/lab-sunscreen.pdf

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Chemistry: Exploring Photochemistry & the Electromagnetic Spectrum UV Bead Lab

Purpose: *In this lab you will research the types of rays from the sun most commonly associated with skin cancer. You will then qualitatively assess the effectiveness of different SPF rating sunscreens on reducing the effect of UV radiation on skin. You will also assess the effectiveness of different sized ZnO particles on UV ray blocking effectiveness.*

Background: Ultraviolet (UV) rays from the sun are associated with the development of skin cancer. Sunscreens and sunblocks were developed to help protect skin from damage by harmful UV rays from the sun. Sunscreens contain substances that reduce the potential for damage by UV radiation either though chemical or physical means. Chemical means involve chemical substances that absorb into the skin. These substances then absorb UV radiation and undergo a chemical reaction. Physical means involve the use of minerals, like zinc oxide (ZnO), that work by sitting on top of the skin and deflecting or scattering the UV rays.

Research and Pre-lab Questions

Instructions: Answer each of the questions below prior to the day of the lab. You may use your class notes and the internet to help you. Filter your internet search results by using site.gov and site.edu domains for your search. Make sure your answers are in complete sentences. Answers involving calculations should include all work and the correct number of significant figures.

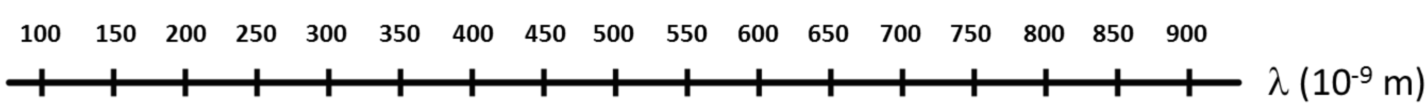
1. Ultraviolet (UV) radiation comprises a portion of the electromagnetic spectrum we studied earlier. Answer the following questions related to UV radiation.

   a. UV radiation is divided into three bands. What are they? Include the wavelengths for each band. Don't forget units!

   b. Which UV band is blocked mostly by the upper atmosphere?

   What are the health risks (biological damage) posed by the remaining two bands you identified above?

   c. Below is a portion of the electromagnetic spectrum. Using vertical lines, NEATLY label the wavelengths (λ) of the three regions of UV radiation you found in 1.a above.



d. The human eye will see wavelengths from about 390 – 700 nm. Neatly label the visible light spectrum on the spectrum above. Can your eyes see UV light? Explain your answer

e. UV beads found in many crafts and toys change color when they are exposed to the UV rays in sunlight. The color change happens because a dye molecule added to the plastic changes shape when exposed to UV light.

The bead color change happens for UV light with a 300-400 nm λ. Using the electromagnetic spectrum in 1.c above, label the section of wavelengths corresponding to the color change for the UV beads.

f. Which of the three bands you identified for UV radiation has the highest energy? Lowest? Place them in sequence below from for lowest to highest. Explain your answer!

g. The UV light source we will be using today has a wavelength of around 390 nm. Label with an arrow the wavelength corresponding to the UV light source on the portion of the EM spectrum in 1.c above.

2. Define the following terms:

Sunscreen

SPF

SAFETY:

- Notify the instructor if you are allergic to sunscreen before starting the lab.
- UV light can damage your eyes, wear UV safety goggles while using the UV light source. Do not stare at the light or point it in any person's direction. Avoid prolonged skin exposure to the UV light.
- Use caution when using the hot plate.
- Wash hands thoroughly when finished and before leaving the lab.

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Part 1: Chemistry of UV sensitive beads

Instructions: In this part of the lab you will be using a UV light and UV sensitive plastic beads that change color when exposed to UV radiation. In experiment 1 you will compare the properties of several different SPF sunscreens that use chemical means to absorb UV radiation. In experiment 2 you will observe temperature effects on UV beads and in experiment 3 you will explore the effect of wavelength on UV bead color.

MATERIALS

365 nm & 390 nm UV Light source(s)	Stop watch	SPF 15, 30, 50, 70 sunscreens
UV beads	Unknown sunscreen	hot plate
Eight small test tubes	250 mL beaker	Test tube holder

Optional: A G2V type yellow dwarf, main sequence star

Procedure

1. **Obtain and wear goggles.**	
2. Get 5 small test tubes. Using the marker provided, label one "Control". Label the remaining tubes "15", "30", "50", "70" respectively	

3. Put four (4) of the same color UV sensitive beads in each of the five test tubes.
o Make observations about the beads.
o Using only the "Control" test tube of UV sensitive beads:
    o Turn the 390 nm UV light source on and place the source about 3 inches from it. Leave the UV light on for 10-15 seconds.
    o Turn off the UV light.
o Use your cell phone camera to take a picture of the beads for future reference
o Make observations, noting the color change. To make observations regarding color consistent, use the following descriptive vocabulary:
    o "White" – No color change
    o "Light" – Some color change
    o "Medium" – Color change between "light" & "Dark/Intense"
    o "Dark/Intense" – Most color change
	Observations:

4. Allow the beads to return to their original color while you proceed to step 5.	Observations:

EXPERIMENT ONE

In the next part of the lab you will observe the effectiveness of different SPF sunscreens at blocking UV rays. You will apply a different SPF sunscreen to the test tubes you labeled in Step 2 and then compare them when exposed to UV light.

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<table>
<tr><td>

5. Take your SPF 15 test tube of UV sensitive beads to an area of the room that is away from your bench and clear of other students.
    - Using the SPF 15 sunscreen spray apply an even/smooth coat of sunscreen.

Hints for success: Ensure a smooth, even coat of sunscreen is applied by:

- Holding the spray about 8 inches from the test tube. Spray about 1 sec at a time. Be consistent with amount you spray.
- Avoid over spraying. Only apply enough to achieve a smooth, even layer. No "runs/drips"
- Rotate the test tube so an even amount is applied.
- Place the test tube in the test tube rack. Avoid scraping or smearing the sunscreen.

</td><td>Observations:</td></tr>
<tr><td>

6. Repeat Step 5 above for each of the remaining test tube and sunscreen combinations. Apply SPF 30 to the test tube labeled SPF 30, etc.
    - Arrange the five test tubes in a row in order of control, 15, etc. Place them in the bottom row of your test tube holder so they will have the best exposure to the UV light.

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<tr><td>

Predict: Before going to the next step make a prediction regarding what you think will happen when the test tubes with UV beads in them are exposed to the UV light.

7. Turn the UV light source on the brightest setting and place the source about 3 inches away from them. Leave the UV light on for 10-15 seconds, then turn off the UV light.
8. Use your phone camera to take a picture and make observations, noting the color change and record your data in Data Table #1.

<u>**Use your picture of the beads for future reference**</u>**!**

</td><td>

Prediction:

Observations:

</td></tr>
<tr><td colspan="2">

Identifying the SPF of an unknown sunscreen. There is a sunscreen of unknown SPF on the counter. Using your data, pictures, and procedures used so far, design an experiment to determine the estimated relative SPF of the unknown sunscreen. Write your procedure below in #7 and observations.

</td></tr>
<tr><td>**Unknown Sunscreen Procedure:**</td><td>

Observations:

Estimated relative SPF of the unknown:

</td></tr>
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EXPERIMENT TWO **In this part of the lab you will observe the effect of temperature on color change of the UV beads by timing how long it takes for the beads to change back their original color**	
9. Fill the 250 mL beaker about 2/3 full with tap water and place on the hot plate. Heat the water (do not allow it to boil) on the hot plate while you perform the next step.	
10. Get two small test tubes and number them #1 and #2.	
11. Place 4-5 UV beads of the same color in each of the two small test tubes. Get your stopwatch ready.	
12. Hold the 390 nm UV light source 2-3 inches from the test tubes on the brightest setting for approximately 10 seconds to cause the UV beads to change color.	
13. Turn off the UV light and start the stopwatch. Place test tube #1 in the beaker of warm water. Time how long it takes the beads in test tube #1 and test tube #2 to change back their original color.	Time test tube #1: ________________(sec) Time test tube #2: ________________(sec)
EXPERIMENT THREE **In this part of the lab you will observe the effect UV wavelength on color change by comparing two different wavelengths with three different color beads**	
14. Get a large weighing boat and then using the marker divide the bottom of the weighing boat into three equal sections (like a pizza slice). o Label one section “Y” for yellow, another section “G” for green, and the last section “B” for blue.	
15. Add colored beads to each section as follows: o 4 yellow beads section “Y” o 4 green beads section “G” o 4 blue beads section “B” **BE CAREFUL NOT TO MIX BEADS IN THE WRONG SECTION!!**	
16. Using the **390 nm UV light only**, hold the light source 2-3 inches from the beads on the brightest setting for 30-40 sec. Turn off the UV light, take a picture, and record your observations Record your observations in Data Table 2 while allowing the beads to return to their white color before going to the next step.	Observations 390 nm UV light: Yellow beads: Green beads: Blue beads:

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17. Using the **365 nm UV light only**, hold the light source 2-3 inches from the beads for 30-40 sec. Turn off the UV light, take a picture, and record your observations Record your observations in data table 2	Observations 365 nm UV light: Yellow beads: Green beads: Blue beads:
15. When you are finished: ○ Put the beads back in the container in the front of the lab. ○ Dispose of the bags in the trash	

Data Table 1

Test tube number	SPF	UV Light Bead Detector Color Intensity	UV Protection (rank from 1 -5 with 5 highest protection)
Control	none		
1	15		
2	30		
3	50		
4	70		
UNK	???		

Data Table 2

Weighing Dish Section	Color of Beads before UV light	Observation of bead color for 390 nm UV light	Observation of bead color for 365 nm UV light
Y			
G			
B			

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Post-Lab Questions:

1. Analyze the results in data Table 1. Complete the table by ranking each from lowest to highest UV protection (1 lowest, 5 highest). What evidence from your experiments with the UV beads supports their claimed SPF values?

2. The UV beads change color when a dye molecule in the bead changes shape. A source of energy is required for the dye molecule to change. What form of energy is absorbed to cause the molecule to change?

3. Which SPF sunscreen absorbed the most UV radiation? Use evidence to justify your answer.

4. What do you estimate the relative SPF of the unknown sunscreen is? Use evidence to justify your answer.

5. Is the UV bead color change evidence of a chemical or physical change? Explain.

6. In Experiment 2 which beads changed back to their original color faster, test tube #1 or test tube #2?

   What can you conclude about the effect of temperature on the speed (rate) of a reaction?

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7. Study the data you recorded in Data Table 2.

   a. Why do you think the yellow beads remained white when exposed to the 390 nm UV light, yet turned yellow in the 365 nm UV light?

   b. What do you observe about the effect of UV wavelength on the color of the blue beads?

   c. The green beads appeared ________________ in the 390 nm UV light, yet appeared ______________ in the 365 nm UV light.

      What can you conclude about the possible composition of the dye molecules in green beads?

      Does this make sense with what you know about colors? (Hint: What combination of colors makes green?)

8. Calculate the energy of the 390 nm and 365 nm UV light. Show all work below. (h = 6.626 x 10^{-34} J•S)

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Part 2: Sunscreen Yellow Highlighter Experiment

MATERIALS

365 nm & 390 nm UV Light source(s)	SPF 50 Zinc oxide (ZnO) sunscreen	Various chemical SPF sunscreens
Yellow fluorescent highlighter	Two (2) Large weighing boats	Small weighing boats
Sponge applicator	White paper	

Background: Sunscreens that use chemical or physical means for UV radiation protection. Sunscreens that physically block UV rays use minerals like ZnO which is the most common mineral used in sunscreen. ZnO is a physical blocker. This means that it scatters or deflects the UV radiation rather than undergoing a chemical reaction. Chemical sunscreens utilize a chemical reaction with the UV rays to protect.

Instructions: In this part of the lab you will prepare two ZnO sunscreen solutions that have different size ZnO particles. You will then assess their effectiveness using a yellow fluorescent marker. You will also observe the UV absorption ability of sunscreens

Part A: Preparation.

1. **<u>Obtain and wear safety goggles.</u>**	**<u>Review Safety Precautions</u>**
2. On the blank side of a white piece of paper, make five 2.5 cm squares in a 1 x 5 pattern and separate the squares by 1-2 cm. Then use the yellow fluorescent highlighter to color in each square. Highlight twice, once using horizontal strokes and a second time using vertical strokes. Label square 1 “control”. Label one of each of the remaining squares for each of the SPF sunscreens to be tested.	
3. Using the 390 nm UV light observe the yellow highlighter squares and record your observations.	**Observations:**
4. Obtain 4 small weighing boats. Label each to correspond with each tested sunscreen. Place a small sample of each sunscreen in the appropriate weighing boat	
5. Obtain 4 sponges, one for each sunscreen to be tested. Be sure not to mix them up!	
Predict: In the next step you will apply a different sunscreen to 4 of the squares. Make a prediction regarding what you think will happen in each square with sunscreen applied when the paper is exposed to the 390 nm UV light source.	**Prediction:**

6. Using separate sponge applicators: a. Apply a thin layer of each SPF sunscreen to the appropriate square. Tip: Evenly apply a thin layer of similar quantities of each sunscreen. Be careful to avoid over applying and use consistent amounts.	
7. Place the paper under the 390 nm UV light source and use your phone camera to take a picture and record your observations of each square.	**Observations:**
8. Repeat step 7 using the 365 nm UV light source. Again, use your phone camera to record your observations.	**Observations:**
9. Dispose of the paper and left-over sunscreen in the trash.	

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Post-Lab Questions & Conclusions:

1. Does sunscreen protect against UV radiation? Justify your answer using evidence from your observations.

2. Describe the effect of the sunscreen on the highlighter fluorescence when the UV light was 390 nm vs. 365 nm. Were there any differences?

What can you conclude about sunscreen effectiveness vs. wavelength of the UV rays?

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Lab Part 1 Optional Guided Inquiry Extension for Advanced Learners

Instructor Notes:

- For more advanced learners the following Part 1 guided inquiry lab using unknown SPF sunscreen solutions may be substituted as an extension.

- The Part 1 lab procedure that follows should be substituted for the more detailed Part 1 procedure above following the "Materials" section of Part 1.

- The extent of instructor guidance to facilitate student inquiry may be tailored to the individual class. The following suggestions are provided:
    - Suggested guiding question: "How can UV sensitive beads be used to evaluate sunscreen effectiveness?"
    - Students work in pairs with a partner to develop a procedure.
    - Include computational differentiated instruction questions such as:
        - Calculate the energy of the UV light source given the wavelength
        - Given the wavelength of the UV light is 390 nm, what is the energy of the radiation being absorbed by the UV sensitive beads?
    - Procedures should be approved by the instructor before starting.

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Chemistry Sunscreen Inquiry Lab

Qualitative comparison of UV-absorption protection vs SPF using UV sensitive beads

*Instructions: In this part of the lab you will **design an investigation to determine the relative SPF levels of four unknown sunscreens (A though D).***

You may use any of the materials provided. Your investigation must include the following in order to be considered valid:

1. *A list of materials*
2. *A neatly written procedure that clearly explains what you did*
3. *Data table(s) that summarizes your results and observations*
4. *Conclusions derived from observations that clearly support your answers*

When designing your experiment(s) ensure that NO SUNSCREEN TOUCHES ANY BEADS.

Instructor Approval: ________