Absorption of Light Energy

Light, Energy, and Electron Structure

Introduction

Why does the color of a copper chloride solution appear blue? As the white light hits the paint, which colors does the solution absorb and which colors does it transmit? In this activity students will observe the basic principles of absorption spectroscopy based on absorbance and transmittance of visible light.

Concepts

- Spectroscopy
- Absorbance and transmittance
- Visible light spectrum
- Quantized electron energy levels

Background

The visible light spectrum (380–750 nm) is the light we are able to see. This spectrum is often referred to as "ROY G BIV" as a mnemonic device for the order of colors it produces. Violet has the shortest wavelength (about 400 nm) and red has the longest wavelength (about 650–700 nm).

Many common chemical solutions can be used as filters to demonstrate the principles of absorption and transmittance of visible light in the electromagnetic spectrum. For example, copper(II) chloride (blue), ammonium dichromate (orange), iron(III) chloride (yellow), and potassium permanganate (red) are all different colors because they absorb different wavelengths of visible light.

In this demonstration, students will observe the principles of absorption spectroscopy using a variety of different colored solutions. Food coloring will be substituted for the orange and yellow chemical solutions mentioned above. Rare earth metal solutions, erbium and praseodymium chloride, will be used to illustrate line absorption spectra.

Materials

Copper(II) chloride solution, 1 M, 85 mL

Erbium chloride solution, 0.1 M, 50 mL

Potassium permanganate solution ($KMnO_4$), 0.001 M, 275 mL

Praseodymium chloride solution, 0.1 M, 50 mL

Water, deionized

Beaker, 250-mL

Black construction paper, 12″ × 18″, 2 sheets

Colored pencils

Diffraction grating, holographic, 14 cm × 14 cm

Microchemistry solution bottle, 50 mL, 6

Overhead projector and screen

Red food dye

Stir rod, glass

Tape

Yellow food dye

Safety Precautions

Copper(II) chloride solution is toxic by ingestion and inhalation. Potassium permanganate is a strong oxidizing agent. It is irritating to the skin and eyes and slightly toxic by ingestion. Wear chemical splash goggles and chemical-resistant gloves while preparing solutions. Wash hands thoroughly with soap and water before leaving the laboratory. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

1. Transfer the copper(II) chloride (blue) and potassium permanganate (red) solutions to labeled microchemistry solution bottles. Fill each bottle as close to the top as possible without spilling. Any extraneous room will cause air bubbles to show when the bottle is turned on its side and can interfere with the electromagnetic spectrum appearance.
2. Prepare a yellow solution by placing 200 mL of deionized water into a 250-mL beaker. Add one drop of yellow food

dye and stir. Transfer the solution to a microchemistry bottle.

3. Prepare an orange solution by placing 200 mL of deionized water into a 250-mL beaker. Add two drops of red food dye and stir. Transfer the solution to a microchemistry bottle.
4. Transfer the erbium chloride and praseodymium chloride solutions into appropriately labeled microchemistry bottles.

Procedure

Part A. Displaying an Overhead Visible Light Spectrum

1. Obtain two sheets of black construction paper.
2. Form a 2-cm wide slit in the center of the stage of the overhead projector using two sheets of black construction paper. Position the slit on the stage so that the image of the slit projected onto the projection screen is vertical (refer to Figures 1 and 2).
3. Place the holographic diffraction grating film above the lens of the overhead projector (see Figure 1). Wear gloves when handling the diffraction grating. If the spectra are not projected to the left and right of the screen, rotate the diffraction grating 90 degrees (the alignment of the grating is important). Once two bright spectra (mirror images of each other) are displayed horizontally to the left and right of the film screen (see Figure 2), the diffraction grating should be secured to the lens with tape. Tape only the outside edges of the diffraction grating and make sure the diffraction grating is flat.
4. Adjust the focus of the overhead projector so that the image of the slit is in sharp focus on the screen. The two spectra should also come into focus.
5. Once the slit is aligned so the "selected" spectrum is in the proper location to be viewed by the students, the construction paper should be secured to the overhead projector with tape.
6. Several activities can be performed to demonstrate the principles of light absorption and transmittance.

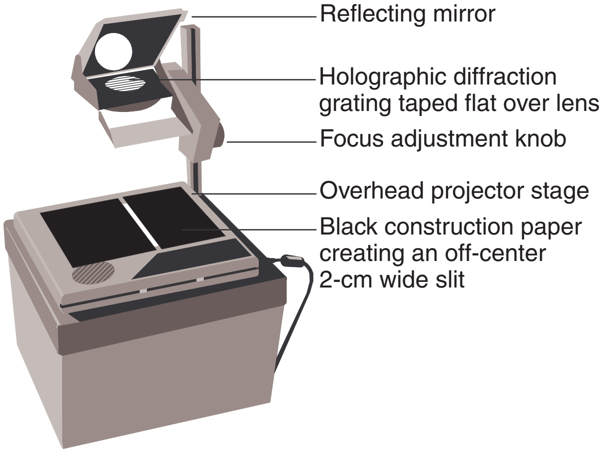


Figure 1. Overhead Projector

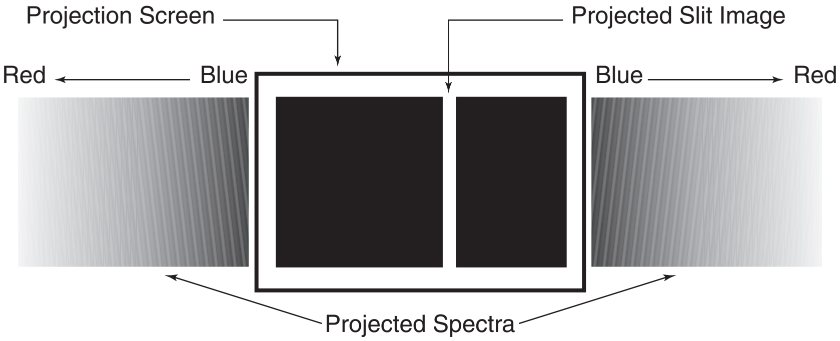


Figure 2. Projected Spectra

Part B. Absorption Spectra

1. Place the overhead projector 10–15 feet from the projection screen.
2. Turn on the overhead projector and aim the light at the projection screen. Eliminate as much light in the room as possible by turning off lights and closing window blinds or curtains. *Note:* The visibility of the spectrum will be best in a very dark room.
3. Position the overhead so one of the two vertical spectra is on the screen or flat wall. Rotate the overhead stand 15–20° to the right or left so the spectrum is centered.
4. Have students observe the appearance of the visible spectrum without any filters in place.
5. Ask students to sketch the observed spectrum on the Absorption Spectrum Worksheet using colored pencils.
6. Place the orange solution in the middle of the overhead projector stage across the 2-cm slit opening. The bottle should be placed on its side, cap pointing either left or right, not up and down, so that the side with the most surface area is touching the overhead.
7. Have students draw the color spectrum they observe in the appropriate box of the worksheet.
8. Discuss with students which colors are absorbed (blue and violet—hence the black spot where those colors used to be) and

which colors are being transmitted (green, yellow, orange and red—the colors that are still visible).

9. Remove the orange solution and repeat steps 6–8 three more times using the copper(II) chloride (blue), potassium permanganate (red), and yellow solutions.
10. Remove all bottles from the overhead projector screen. Hold up the praseodymium chloride solution. Have students note the color and predict what they expect to see based on the results obtained with the other solutions.
11. Initial observations will be different as all the colors in the spectrum are present, as well as several dark, fine lines. Closer examination will reveal two significant lines in the blue-violet region. Have students sketch the absorption lines on the worksheet.
12. Repeat steps 10 and 11 using the erbium chloride solution.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Potassium permanganate may be disposed of according to Flinn Suggested Disposal Method #12a. Copper(II) chloride may be disposed of according to Flinn Disposal Method #26b.

Tips

- As an extension to this activity, make "artificial" purple and blue solutions and see if they yield the expected results when used as light filters.
- To optimize spectrum viewing, the microchemistry bottles should be as full as possible. Once each solution has been transferred to the microchemistry bottle, fill any remaining space with distilled or deionized water using a Beral pipet.
- Acrylic or gelatin light filters may be used in place of the colored solutions. The same principles will apply.

Discussion

White light is composed of wavelengths of light from the visible spectrum as well as light wavelengths that are invisible to our eyes (i.e., infrared and ultraviolet). The visible spectrum is often referred to as "ROY G BIV" after the colors of light that are produced when white light is transmitted through a prism: red, orange, yellow, green, blue, indigo and violet.

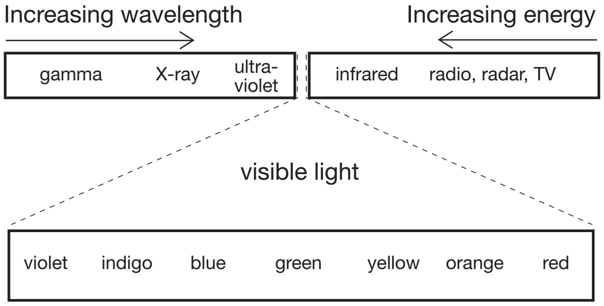
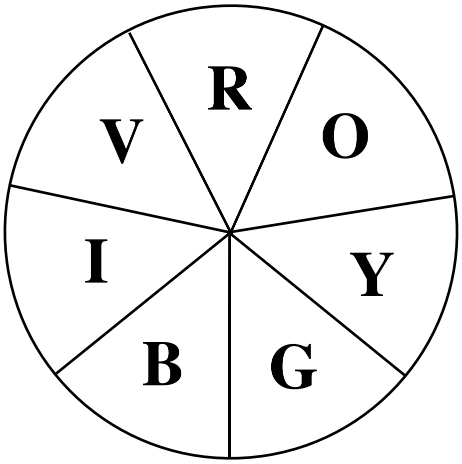


Figure 3.

The color of an opaque object results from the reflection of light from that object. Grass appears green when exposed to white light because the "green-colored" light waves that compose the white light are reflected from the surface of the grass and the other wavelengths ("blue," "red," "yellow," etc.) are absorbed. The green wavelengths of light reflect back to our eyes and interact with the cones in the retina of the eye. The cones are the color receptors of the eye. Our brain receives the signals sent from these cones and interprets that our eyes are seeing the color green. However, most materials do not reflect a pure single wavelength color and absorb all the other colors in the spectrum. Most materials reflect a combination of colors from the visible spectrum; this gives objects their own distinctive colors. Wavelengths and intensities of light generate an enormous variety of colors that we see.

The color of a transparent solution or material in visible light corresponds to the color of light transmitted or passed through the solution. The solutions used in this demonstration are examples of white light filters. For example, a solution that appears yellow absorbs mostly violet light—most of the other colors in the visible spectrum are transmitted and thus observed in the projected spectra. See the *Observations* below for a description of the relationship between the color of each solution and the colors that are absorbed. Spectroscopy is defined as the measurement of the amount or intensity of light or electromagnetic



energy absorbed by a substance as a function of the wavelength. Different types of absorption spectroscopy result from different types of radiation used, namely X-ray, UV, visible, infrared, etc. The absorption of visible light by a substance results from the excitation of electrons to higher energy levels. Because electron energy levels are quantized, different substances absorb different colors of visible light. The visible absorption spectra of transition metal ions consist of fairly broad bands due to d-electron transitions.

In contrast, many rare earth metals exhibit fine line absorption spectra. (These spectra are indeed "rare.") The absorption peaks appear as sharp, discrete dark lines against a colored spectrum. They result from electron transitions involving the f orbitals. The relationship between the colors of absorbed vs. transmitted light is evident of the concept of *complementary colors*.

In general, colors opposite each other on the color wheel are complementary colors. For example, by looking at the wheel, the fact that violet (purple) and yellow are complementary colors can be seen. Therefore, in analogy to the red filter, it can be assumed that the violet filter absorbs yellow light and transmits violet light. The color wheel and the idea of complementary colors can be used as a first estimation of the wavelengths that are absorbed by a substance based on its color.

The following table lists the wavelengths associated with each of the colors in the visible spectrum and their complements. The representative wavelength can be used as a benchmark for each color. For example, instead of referring to green as light in the wavelength range 500–600 nm, one could simply say that green light is 520 nm.

Representative Wavelength, nm	Wavelength Region, nm	Color	Complementary Color
410	400–425	Violet	Yellow-green
470	425–480	Blue	Orange
490	480–500	Blue-green	Red
520	500–560	Green	Red-Violet
565	560–580	Yellow-green	Violet
580	580–585	Yellow	Violet
600	585–650	Orange	Blue
650	650–700	Red	Blue-green

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
  Evidence, models, and explanation
Content Standards: Grades 5–8
  Content Standard B: Physical Science, transfer of energy
  Content Standard C: Life Science, structure and function in living systems
Content Standards: Grades 9–12
  Content Standard B: Physical Science, interactions of energy and matter
  Content Standard C: Life Science, the cell

Answers to Worksheet Questions

Observations

The sketches should resemble the electromagnetic spectrum with the appropriate colors that are observed or transmitted shown in color. The regions (colors) of the spectrum that are absorbed will appear black or very dark. Below is a list of the colors that should appear in each box.

Potassium permanganate (red solution)—blue, indigo, violet, red and orange are observed (transmitted)
Copper(II) chloride (blue solution)—red, orange, yellow, green, blue, and violet are observed
Orange solution—green, yellow, orange and red are observed
Yellow solution—red, orange, yellow, green, and blue are observed
Praseodymium chloride—absorption line present between the orange and yellow, there are additional lines in the blue and violet.
Erbium chloride—major absorption lines in the green with faint lines in the red and blue

Answers to Post-Lab Questions

1. Compare the relationship between the blue solution and orange solution in terms of their absorbance of visible light and give the definition of complementary colors.

   Blue and orange are complements of each other. Thus, the orange solution absorbs blue light and the blue solution absorbs orange light.

2. If a green solution had been placed on the overhead, predict which colors of light would be absorbed and which colors would be allowed to pass through.

   Red would be absorbed and green, yellow, orange and violet would be transmitted.

3. What do the spectra of the rare earth elements, erbium and praseodymium, demonstrate?

   They demonstrate fine line absorption spectra. The absorption lines correspond to energy transitions involving electrons in the f orbitals.

4. Did erbium and praseodymium yield the results you initially predicted? Why or why not?

   The erbium did support the hypothesis because there were major absorption lines in the green and yellow-green, and faint lines in the red and blue. The praseodymium did not support the hypothesis that it should absorb bands in the red/orange region. There was a strong absorption line between the orange and yellow; there is also an absorption line in the blue and violet regions.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Absorption of Light Energy* activity, presented by Annis Hapkiewicz, is available in *Light, Energy and Electron Structure* and in *Absorption Spectroscopy*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Absorption of Light Energy* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Absorption Spectroscopy—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP8823	Absorption Spectroscopy—Chemical Demonstration Kit
C0212	Copper(II) Chloride, Reagent, 25 g
P0077	Potassium Permanganate, Reagent, 100 g
V0003	Food Coloring Dyes, Dye Set
AP1047	Holographic Diffraction Grating Film
AP1449	Mircrochemistry Solution Bottle, 50 mL
P0269	Praseodymium Chloride Solution, 0.2 M, 50 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Absorption of Light Energy Worksheet

Observations

Draw your observations in the seven boxes below using colored pencils.

Electromagnetic spectrum

Potasium permanganate

Copper(II) chloride

Yellow solution

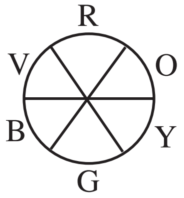
Orange solution

Erbium chloride

Praseodymium chloride

Post-Lab Questions

Use the pie chart presented to assist in answering Questions #1 and #2. Colors opposite each other on this wheel are known as complements.



1. Compare the relationship between the blue solution and orange solution in terms of their absorbance of visible light and the definition of complementary colors?

2. If a green solution had been placed on the overhead, predict which colors of light would be absorbed and which colors would be allowed to pass through.

3. What do the spectra of the rare earth elements, erbium and praseodymium, demonstrate?

4. Did erbium and praseodymium yield the results you initially predicted? Why or why not?