

Colors Experiment EP09

Part A: The Additive Process

Part B: The Subtractive Process

Time Required for Completion: Approximately 65 minutes.

Lab Report Grading Guide: Introduction (10 pts), Data (0 pts), Data Analysis [Narrative (30 pts) & Analysis Questions (50 pts)], Conclusion (10 pts).

OBJECTIVES

- To investigate the additive process of mixing colors by using optical equipment to study the colors of light, the mixing of light, and the colors of objects and how the perceived colors of the objects relate to the actual colors of the wavelengths of light they reflect
- To investigate the subtractive process of mixing colors by combining a variety of pigments and observing the resulting colors

EQUIPMENT NEEDED

Experiment Apparatus:

Pasco™ Introductory Optics Kit (OS-8500) Desk Lamp (2) w/40W bulbs (1 White, 1 Red)

Lab Beaker, 250 mL (3) Masking Tape

Printer's Ink, Cyan Disposable Pipette (3)

Printer's Ink, Yellow Paper Towels

Printer's Ink, Magenta Disposable Latex Gloves

Disposable Stirrers (3) Aluminum Mixing Tray

THEORY

Early investigators assumed that light in its purest and simplest form was white, and that refractive materials alter the characteristics of the white light to create the various colors. Sir Isaac Newton was the first to show that ***light, in its simplest form, is colored***; and that refractive materials (lenses and prisms) merely separate the various colors that are the natural constituents of white light.

White light consists of all the colors present in the visible light spectrum. Each of these colors has a different **wavelength frequency** within the spectrum. From longest to shortest wavelength, (~ 750 to 390 nm), the colors are: *Red, Orange, Yellow, Green, Blue, Indigo, and Violet*.

When white light strikes most objects, certain colors of light are reflected, while others are absorbed. What color is reflected or absorbed depends on the natural vibration frequencies of the atoms and molecules that are present in an object's atomic matter. More specifically, electrons of one kind of atom vibrate over a range of wavelength frequencies different from the range of other kinds of atoms.

At **resonant frequency**—where the amplitude of oscillation is large—light is absorbed. But ***below and above resonant frequency, light is retransmitted***. Retransmitted light passes through transparent material. If the material is opaque, the retransmitted light is reflected back into the medium from which it came. ***The color that you see is the reflected (retransmitted) light.***

Color and the Human Eye:

Color is the way your eye interprets the wavelengths of light. Each combination of wavelengths provides its own sense of color. Unfortunately, our eye's ability to distinguish between wavelengths is not perfect. There are two types of cells that respond to light entering the retina of your eye. **Rods** are light sensitive and allow you to see in dim light, while **Cones** detect color and provide sharpness control over the image you see. The cones do not work in dim light, and that is why you have difficulty perceiving sharp images or colors in the dark.

The retina has three kinds of cone cells and each kind of cone cell is sensitive to a different set of wavelengths. **Blue receptors** respond only to the short wavelengths. **Green receptors** react to wavelengths in the middle of the spectrum. **Red receptors** respond to the longest wavelengths in the spectrum. Although each type of receptor has some overlap with the frequencies covered by the adjoining receptor, in humans, the widest range of frequencies is covered by the green receptors.

Some people are unable to see certain colors. Approximately 7% of men and less than 1% of women are unable to distinguish red from green. These people are **colorblind**. Although rare, total colorblindness does occur, and the person so afflicted cannot distinguish any colors at all.

Absorption and Reflection:

Most materials absorb some frequencies and reflect the rest. In the case of white and black, *white reflects all colors and black absorbs all colors*. In actuality, both do not fully reflect or absorb light and a very small amount of light is absorbed by white and reflected by black. Otherwise, we would not be able to see white or black objects.

However, *an object can reflect only the frequencies that are present in the illuminating light*. Thus the appearance of a colored object depends on the kind of light used.

This is why an object illuminated by candlelight seems dimmer, softer, and generally has a yellow tinge, and why objects viewed under Fluorescent lighting seem harsher in appearance. Bright sunlight allows for the easiest detection of true color on an object.

All the colors you see can be made with only the **primary colors** of **red, green, and blue**. How these colors combine can be better understood by studying the **primary color model**. If you focus individual beams of red, blue, and green light onto a white surface, two primary colors combine to form a secondary color where the beams overlap.

The **secondary colors** are: **yellow** (red + green), **magenta** (red + blue), and **cyan** (green + blue). *Where all three primary colors overlap, your eyes see white*.

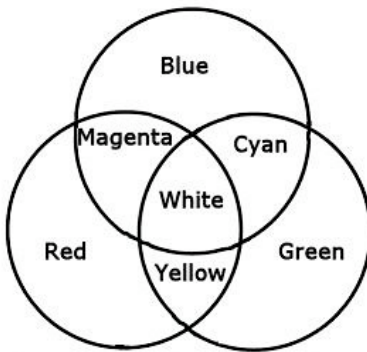
Mixing Colors of Light and Mixing Pigments:

Mixing Colors of Light: If you begin with white light and subtract some color from it, the resulting color will appear as the complement of the one subtracted. **When you mix colors of light, the process is called color mixing by addition.**

Light Filters: A **color filter** is made of a material that will absorb some wavelengths of light while allowing others to pass through.

If you use a primary-color filter, only light that is of matching wavelength to the primary color of the filter passes through. In example, if you were to look at a white light through a red filter, the filter absorbs all the light except for the longest wavelength (red). Green and blue light is absorbed and only the red light passes through the filter.

Primary Color Model



Colors produced when model lights are of equal brightness and shown on a white screen

If you use a secondary-color filter, a primary color is absorbed. In example, a yellow filter absorbs blue light but allows both red and green light to pass through. Color slides commonly make use of three filters, one of each of the secondary colors. Each filter absorbs one primary color and allows the remaining wavelengths of light to pass through.

Imagine that you have a slide with a picture of a fire engine. When the projector sends white light through the slide, the magenta filter absorbs the green light and the yellow filter absorbs the blue light. Only the red light passes through to the viewing screen and thus, the fire engine appears in its normal color of fire engine red. When three secondary color filters, cyan, magenta, and yellow are combined, the result is black.

Complementary Colors: *Any two colors of light that appear white when added together are called complementary colors.* In example, if you combined cyan and red, you will get white because red and cyan are complementary colors. Recall that the combination of red, green, and blue light also appears white. In effect, the cyan substitutes for individual blue and green lights because cyan is composed of blue + green (no red).

COMPLIMENTARY COLORS			
Mix Primary Colors	Produce Secondary Color	Mix Colors	Produce Complimentary Color
Red + Green	Yellow	Blue + Yellow	White
Red + Blue	Magenta	Green + Magenta	White
Blue + Green	Cyan	Red + Cyan	White

(**Note:** Every hue has some complementary color that when added will produce white.)

Mixing Pigments: *Materials that have special color properties that are used to color other materials are called pigments.* By absorbing some colors and reflecting the rest, pigments produce the perceived colors of paints and dyes. **The process of mixing paints and dyes is an entirely different process from the mixing of colored light. When you mix pigments, the process is called color mixing by subtraction.**

Paints and dyes contain finely divided particles of solid pigment that absorb certain frequencies and reflect other frequencies. The part that is absorbed is in effect, subtracted from the incident light. For example, if white light falls on a pigment that absorbs blue light, the light reflected appears cyan. This absorption and reflection covers a relatively wide range of frequencies, or in short, pigments reflect a mixture of colors.

In theory, pigments combine colors the way filters do. Mixing yellow and cyan should produce green. In reality, this rarely works well because the light rays reflected are not pure colors and each pigment reflects a complicated combination of wavelengths. Although the simple three-color primary model

(red, green & blue) works well in color film, color printing, and displays on TV/computer monitor screens, the model is not very useful in mixing paints. Painters have to rely on experience gained through trial and error in mixing pigmented paints in order to get the shade of color desired.

Part A: The Additive Process

PROCEDURE

• Equipment Setup – The Colors of Light

1. Open up the Pasco Introductory Optics Box and remove and assemble the optical bench components shown in Figure EP09.1.

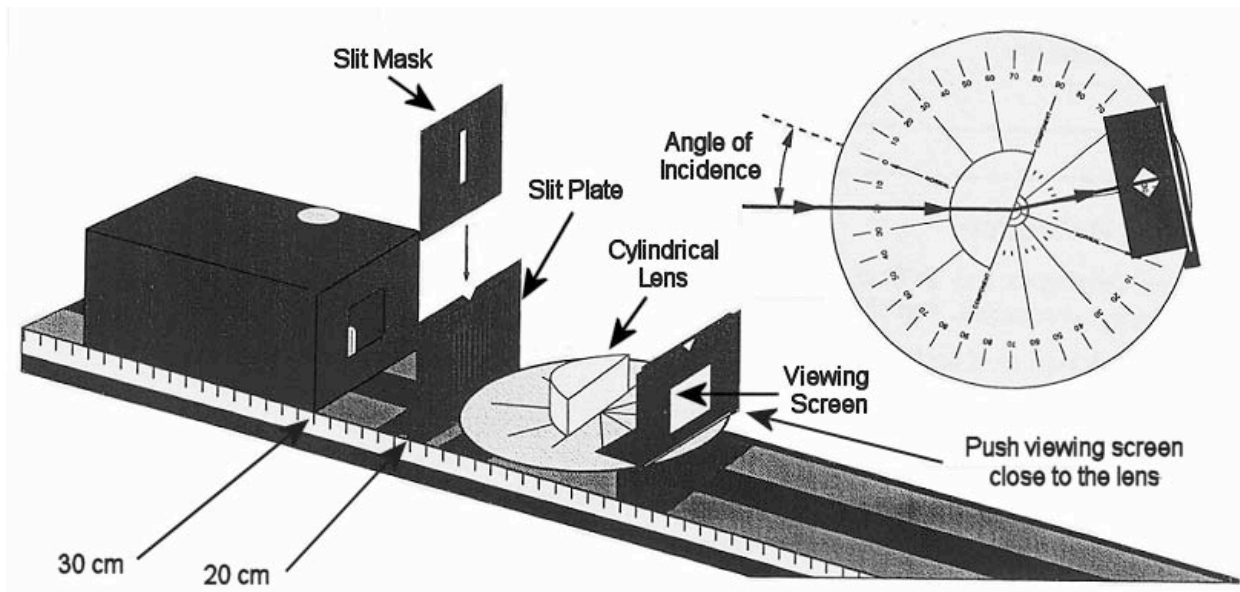


Figure EP09.1 Equipment Setup – The Colors of Light

• Data Collection – The Colors of Light

1. Adjust the filters and cylindrical lens so that a single ray of light passes through the center of the Ray Table.
2. Slowly rotate the Ray Table to increase the angle of incidence of the light ray.
3. Examine the refracted ray on the Viewing Screen. Notice the color separation at large angles of refraction. Record your observations in Data Table 1.

• Equipment Setup – Mixing Colored Light

1. Setup the optical bench equipment as shown in Figure EP09.2.

• Data Collection – Mixing Colored Light

1. Arrange the Cylindrical Lens so that the three central light rays (one red, one green, and one blue) intersect at precisely the same point on the Ray Table.
2. Slowly move the Viewing Screen toward this point of intersection (you'll have to remove it from its component holder). Record your observations in Data Table 2. **Answer analysis question 1** in the Experiment EP09 lab report.

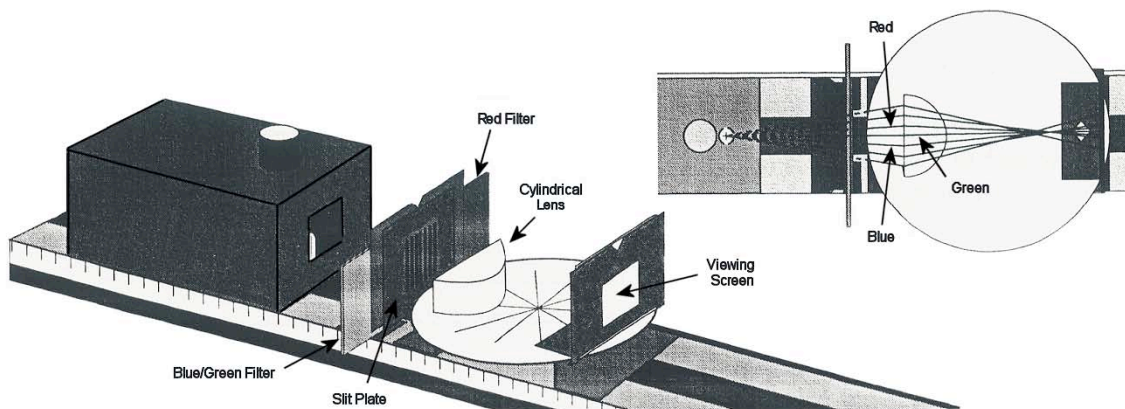


Figure EP09.2: Equipment Setup – Mixing Colored Light

● **Equipment Setup – The Color of Objects**

1. Setup the optical bench equipment as shown in Figure EP09.3.

● **Data Collection – The Colors of Objects**

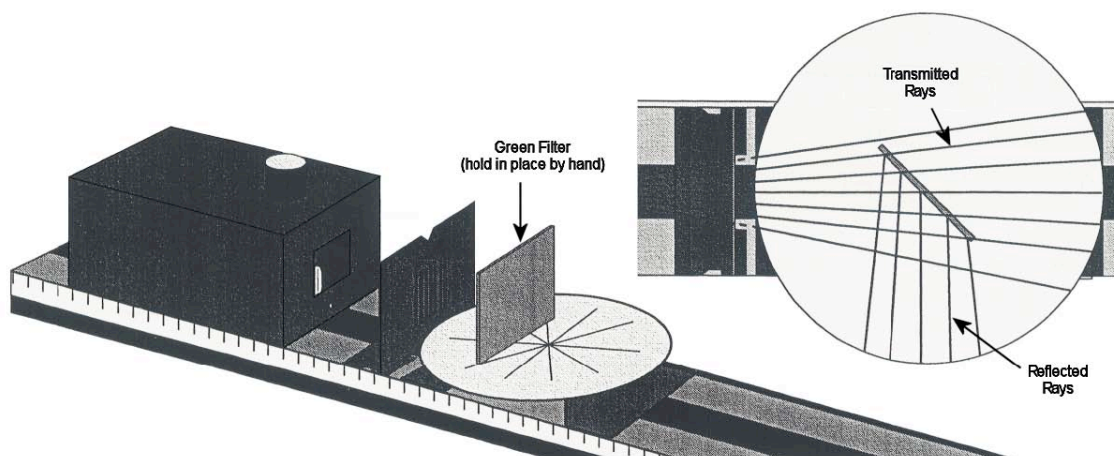


Figure EP09.3 Equipment Setup – The Colors of Objects

1. Observe the light rays that are transmitted and reflected from the Green Filter. Record your observations in Data Table 3. **Answer analysis question 2** in the Experiment EP09 lab report.

2. Place the Red Filter behind the Green Filter (so the light passes first through the Green Filter and then passes through the Red Filter). Look into the Green Filter. Record your observations in Data Table 3. **Answer analysis question 3** in the Experiment EP09 lab report.

3. Place the Blue Filter over the Light Source aperture so that the incident rays are blue. Let these rays pass through the Green Filter only. Record your observations in Data Table 3. **Answer analysis questions 4 and 5** in the Experiment EP09 lab report.

4. Remove the Green Filter and replace it with the Red Filter. Place the Blue Filter over the Light Source aperture so that the incident rays are blue. Let these rays pass through the Red Filter only. Record your observations in Data Table 3. **Answer analysis question 6** in the Experiment EP09 lab report.

5. Disassemble the equipment.

▶ Turn off the unfrosted incandescent lamp. Leave the sodium lamp on. Your instructor will turn off the sodium

- lamp at the end of the lab.
- ▶ Return all optics bench equipment to the appropriate locations in the Styrofoam cushion in the Basic Optics Kit storage box.

Part B: The Subtractive Process

PROCEDURE

• Equipment Setup

1. Put a small piece of masking tape on the front of three **250 mL** lab beakers, the barrel of the three disposable pipettes, and the barrel of the three stirrers. Arrange the items into three sets of 1 beaker, 1 pipette and 1 stirrer. Use a pen to label each set of items as respectively, “C”, “M”, and “Y.”
2. Cover the bottom of the aluminum mixing pan with a double layer of paper towels.
3. Fill each beaker with approximately **100mL** of tap water. Place them side-by-side on the paper toweling in the aluminum mixing pan.
4. Adjust the table lamps at your lab table so that the white incandescent light bulb and red incandescent light bulb shines directly on the three beakers.
5. Designate **one member of the group to act as the color mixer**. The color mixer will put on a pair of disposable latex gloves.

(**WARNING:** Some people have allergic reactions to latex material. If you have such an allergy you cannot be the group member who will act as the color mixer.)

6. Have the color mixer open the bottles of **cyan, magenta, and yellow printer’s ink** and place them in their support base on the paper toweling inside the aluminum mixing pan. (Make sure you have bottles that contain sufficient amounts – more than ¼ full - of relatively fresh ink. The “Y” bottle appears reddish but can be distinguished from the deeper red-purple of “M”).

WARNING: Be very careful when you are handling the printer’s inks during this experiment. The ink can permanently stain your hands and clothing! *Lay out a double layer of paper toweling over the area in which you will conduct your mixing experiment.*

• Data Collection

1. Use the disposable pipettes to add drops of printer’s ink into each of the labeled lab beakers as indicated in Data Table 4. Stir the mixture between additions to achieve a uniform color.

(**WARNING:** To avoid contaminating the mixtures or ink reservoirs, **ensure that you use the corresponding set of items (C, M, or Y) for each color of ink (Cyan, Magenta, and Yellow.)** Do not mix them up or you will introduce an irreversible error into the experiment.)

2. Observe and record the color of the solution for each step during the adding and stirring process. Observe the entire solution in the beaker first under white light, and then under red light. Record your observations in Data Table 4.

ENDING THE EXPERIMENT

1. Disassemble the equipment.

- ▶ Recap the bottles of printer’s ink.
- ▶ Wipe the outside of the bottles with clean paper towels.
- ▶ Place the disposable gloves, disposable pipettes, disposable stirrers, and used paper towels in the trash.
- ▶ Wipe up any spills at your lab station and place the used paper towels in the trash.
- ▶ Pour the contents of all three lab beakers into the lab sink. **(b.)** Thoroughly rinse each of the lab beakers.

- ▶ Dry the beakers with paper toweling and return them to your lab table.
- ▶ Place the used paper towels in the trash.
- ▶ Turn off and unplug the desk lamps.

2. Answer analysis questions 7 through 10 in the Experiment EP09 lab report.

Experiment EP09: Colors

Student Name

Lab Information

Lab Section (Day/Time) Date of Lab

Lab Instructor Date Submitted

Lab Partners

Lab Partner Name Lab Partner Name

Lab Partner Name Lab Partner Name

Lab Partner Name Lab Partner Name

INTRODUCTION (10 pts).

In **one concise paragraph in your own words**, tell what you are trying to prove or test in the experiment (i.e. the purpose.)
In one additional paragraph for each part of the experiment, briefly explain in your own words, the procedure you used to collect the data in that part of the experiment (i.e. what you actually did in the lab.) Do not copy the lab manual procedures word-for-word.

DATA (A separate data section is not required for this report).

DATA ANALYSIS (30 pts)

For each part of the experiment, explain in **one concise paragraph your analysis of your collected data**. Be sure to identify which part of the experiment your analysis is addressing and note any trends or unexpected/unusual results.

ANALYSIS QUESTIONS (50 pts possible)

Answer the analysis questions. Be sure to completely answer each question and as required, show your work.

Part A: The Additive Process

1. (5 pts). What color of light results when red, green and blue are mixed? How does this support Newton's theory? Explain.

2. (2 pts). Green Filter Only: What color are the transmitted and reflected rays?

Green Filter: Transmitted: Reflected:

3. (4 pts). Green and Red Filters: What color are the transmitted and reflected rays?

Green Filter: Transmitted: Reflected:

Red Filter: Transmitted: Reflected:

4. (4 pts). Blue/Green and Green Filters: What color are the transmitted and reflected rays?

Blue/Green Filter: Transmitted: Reflected:

Green Filter: Transmitted: Reflected:

5. (5 pts). What makes the Green Filter appear green? Explain your answer.

6. (4 pts). Blue and Red Filters: What color are the transmitted and reflected rays?

Blue/Green Filter: Transmitted: Reflected:

Red Filter: Transmitted: Reflected:

Part B: The Subtractive Process

7. (4 pts). In general terms, as you added drops of ink, how did it affect the color of the solutions?

8. (4 pts). At what points during the experiment did the color of the 3 different solutions match?

9. (8 pts). Based on your observations, if we had used different proportions of ink in our solutions than prescribed, how would that have affected the color of the solutions?

10. (10 pts). Theoretically, if we mixed an equal part solution of cyan and yellow printer's inks, what would be the resulting color? Show your work in theoretical terms.

CONCLUSION (10 pts).

In **one concise paragraph**, briefly review the lab (objective(s) and note the success or failure of your experimentation in relation to the objective(s). If there were any problems, suggest some specific solutions that could potentially improve the lab results.

DATA TABLES – Experiment EP09

Lab Instructor Signature:

**Data Table 1
The Colors of Light**

Observations:

**Data Table 2
Mixing Colored Light**

Observations:

**Data Table 3
The Color of Objects**

Observations - Green Filter Only:
Observations – Red and Green Filter:

Observations – Blue and Green Filter:
Observations – Red and Blue Filter:

Data Table 4
The Subtractive Process of Mixing Pigments

Beaker "A" Solutions		Color Under White Light	Color Under Red Light
Base Solution	100mL of H ₂ O		
Primary Solution	Base + 2 drops <i>Cyan</i>		
Binary Solution	Primary + 2 drops <i>Magenta</i>		
Tertiary Solution	Binary + 6 drops <i>Yellow</i>		
Beaker "B" Solutions			
Beaker "B" Solutions		Color Under White Light	Color Under Red Light
Base Solution	100mL of H ₂ O		
Primary Solution	Base + 2 drops <i>Magenta</i>		
Binary Solution	Primary + 4 drops <i>Yellow</i>		
Tertiary Solution	Binary + 2 drops <i>Cyan</i>		
Beaker "C" Solutions			
Beaker "C" Solutions		Color Under White Light	Color Under Red Light
Base Solution	100mL of H ₂ O		
Primary Solution	Base + 6 drops <i>Yellow</i>		
Binary Solution	Primary + 2 drops <i>Cyan</i>		
Tertiary Solution	Binary + 2 drops <i>Magenta</i>		