

# LAB 11

## Light and Color

Read Hewitt Chapters 27 and 30

*Bring colored pencils or crayons to the lab if you already have some.*

### What to learn and explore

In the previous lab, we discovered that some sounds are simple, and others are complex combinations of many frequencies. We observed the **spectrum** of many different sounds.

The same is true of light—but it was a bit of a surprise when scientists discovered that colored light can be simple and white light is complex! In today's lab, we will separate light into its frequency **spectrum**, using a “grating,” and discover some of the magic of how light is created by atoms.

When light passes through a “grating” (thousands of slits side by side), the light waves fan out from each slit and the overlapping waves cancel at most angles. At those angles no light is seen. At some angles, however, the light waves combine constructively and add to each other, making bright light. Each different wavelength (thus each different color) is bright at a different angle, so we get a **spectrum**, much like the frequency spectrum of sounds in last week's lab. Today, we will use gratings to observe beautiful spectra and begin to learn about our truly amazing sense of **vision**.

We will also find that the spectrum of a gas is much different from that of a solid, and that laser light has a very special spectrum. We will learn to identify different gases by the light they produce. It is a very pretty lab—if you like colors.

### What to use

Diffraction gratings, slide projector and slit, incandescent lamps, filters, colored objects, gas lamps, Helium-Neon and diode lasers, infrared camera.

### What to do

Experiment with the equipment provided to help answer the questions below and other questions of your own. The experiments are ordered in a roughly logical fashion, but if you have prepared by reading the text, you may skip around and hopefully it will make sense.

### Mandatory Comments

Please use this part of the page to comment on which parts of this lab worked well for you (and which didn't). Thank you.

## 1) Incandescent Light Spectrum

White light is created from a glowing “incandescent” white-hot tungsten filament in a slide projector bulb. We pass this light through a narrow slit, and then through a *diffraction grating*, which spreads the light into a *spectrum* of colors. Notice that there is a spectrum on both sides of a white image of the slit in the middle.

a) Sketch the spectrum and describe the colors you see. How many different color bands would you say there are? (There is not a “right answer” to this.)

b) Incandescent light is created by electrons, which move rapidly but randomly, in the lamp's white-hot metal filament. Are there any “gaps” in the spectrum of this light, or is it a continuous “wash” of frequencies?

c) In what way is the spectrum of white light from the incandescent lamp similar to that of white noise?

d) Human eyes see color in the spectrum by detecting three different color bands: Red, Green and Blue. These “RGB” colors are called the additive primaries and all other colors are mixtures or overlaps of R, G and B. Notice the RGB regions in the spectrum. What color(s) do you see where R and G overlap? G and B?

## 2) Colored Filters

While looking at the spectrum of the slide projector bulb, put a colored filter in front of the grating.

a) What does the filter do to the spectrum of the light? Which of the RGB band(s) does it absorb? Which does it transmit? On the whiteboard, draw the region of color that gets through the filter.

b) Repeat for other filters. Make a general conclusion about what a colored filter does.

c) What happens if you combine filters? Can you predict what RGB colors will get through? (Hint: draw the color regions for each filter separately and see where they overlap).

Then test your predictions – were you right?

### 3) Colored Reflections

Put various white or colored objects in the light spectrum projected on the wall. Note that white objects reflect all light, so they appear bright no matter what color illuminates them. Colored objects absorb some bands of light, and reflect others.

- a) When will a red object look brighter: when illuminated by red light, or by blue light?  
Write down your prediction before testing it.

Were you right?

- b) For each of these colored fabrics, move them through the spectrum to see which colors of light they absorb most. (Hint: when they absorb light, they will appear darker.)

Red object:

White object:

Green object:

Black object:

Blue Object:

### 4) Color addition.

We have hung a white screen on the side wall of the lab, and illuminated it with three overlapping spotlights (R, G and B, of course).

For each of the cases below, predict what you will see, then check your prediction.

| Combination of colors | Predicted Color | Observed Color |
|-----------------------|-----------------|----------------|
| Red and Blue          |                 |                |
| Blue and Green        |                 |                |
| Red and Green         |                 |                |
| All Three             |                 |                |

Note: We have technical terms for these overlapping colors: “blue-green” = **cyan**, purplish, or “red-blue” = **magenta**, and “yellow” = **yellow**.

- e) Experiment with making shadows on the wall (with all three lamps together), by putting a pencil or other object in one or more of the colored light beams. Can you explain the colors you see?

### 5) Color Mix-n-Match Website

On the computer is a color mixing game that lets you add different amounts of red, green, and blue to produce over 16 million different colors. ([www.johnw.org/physicsapps/color.html](http://www.johnw.org/physicsapps/color.html))

**a)** Experiment with different combinations of red, green, and blue to produce different colors. What combination of red, green, and blue are required to produce the following colors (draw a rough sketch of the sliders to show the color amounts):

yellow:

magenta (reddish-purple):

cyan(turquoise):

white:

black:

red:

**b)** Now play the game! Click on the reset button to get a new (random) background color. Try to make the circle match the background. Adjust the balance of the three colors of light by sliding the sliders or for each color (use the arrow keys for fine tuning). When the color of the circle matches the color of the background, the circle will disappear. When you think you've got it, click "Show Answer" to see how well you did. Write down the RGB values for your guess and for the "right answer". Have each person try it at least once.

**c)** How does the computer screen display 16 million different colors? Look closely at the screen, using a magnifier, to see how different colors are produced by the computer monitor. Compare what you see with the picture inside the magnifying glass in the game. (If you don't clearly see little rectangular bars of color, please ask for help.)

### 6) Monochromatic (single color) Light– Red Lamp

A lamp with a red filter produces light of only a single frequency. We hide it in a box to keep out all the room light.

Turn on just the red light and look at the objects in the box. Can you tell what colors they are? Make some guesses.

You know that the objects are reflecting only red light since that's the only light there is in the box. Do they look like dark and light red, or more like black and white? Why do you think this is so? (Hint: Think about the different kinds of detectors in your eyes.)

If all the objects are reflecting red light, why don't they all look exactly the same?

Now turn on the white light and see if your color guesses were right.

**\*\*\* Insight:** You have seen lots of monochromatic lamps—but where? One of the most common types of street lamp is the sodium lamp, which actually produces almost a single frequency. These are particularly common in San Jose. Lick Observatory, a major astronomy research station, is located on top of Mount Hamilton, east of San Jose. The Lick astronomers convinced the City of San Jose to install all sodium street lamps so that city light could be easily filtered out of their star images! The side effect is that your car may look 'wrong' in a parking lot at night in monochromatic light.

## 7) Line Spectra

Lamps containing different gases, such as hydrogen, helium, mercury, neon, argon, or oxygen are set up at the back of the lab. Take a hand-held grating and check them out one at a time. You will notice that their spectra are **not continuous** and that they are all unique!

Each type of gas has a different atomic structure, which causes it to emit its own specific frequencies of light when it is excited by an electric current. This is called a **line spectrum** and it allows us to identify certain gasses like we identify people by their fingerprints.

a) Using the images on the computer as a reference, try to identify each of the three gas lamps from the **line spectrum** that it produces. For each tube, draw (or just name) the most prominent lines in the spectrum and identify the gas inside the lamp.

**Lamp 1:**

**Lamp 2:**

**Lamp 3:**

**Lamp 4:**

b) If you found one of these same frequency patterns in the light from a star, what might you conclude about the star?

c) The light spectra of gases are often likened to the sound spectra of musical instruments. How are these light and sound spectra similar?

\*\*\* **Insight:** Our eyes have only the three receptors for color—the cones. Our ears have a huge number of separate receptors for the frequencies of sound. Mixtures of color (such as these gas lamps) are perceived as a single color. Mixtures of sound can be sorted and often the individual notes can be recognized. With this in mind,

When you look at a gas tube with your bare eyes, how many colors do you see?

How does this compare to playing several notes at the same time on a keyboard in the music lab?

## 8) Laser Light compared to a Continuous Spectrum

Here is an incandescent bulb with red and green laser beams shining together onto the side of the bulb.

a) At first, look at the light bulb with your back turned to block the laser beams. Hold a small grating right up to your eye. Look through the grating at the white light emitted by the bare incandescent filament. Off to the side, you should see a color spectrum of the lamp - the same spectrum you saw in part (1). Again notice that the light from this **white-hot, solid tungsten filament** contains a smooth “wash” of frequencies. We call this a **continuous spectrum**.

Use the big red “Variac” control to adjust the voltage applied to the lamp. Dim the lamp a little bit and answer these questions:

Which color first disappears from the spectrum as the lamp is dimmed?

If you dim it some more, which color goes away next?

If you keep dimming the lamp, what’s the last ‘surviving’ color?

Now that you’ve seen which colors disappear when the energy is lowered, complete the following statement:

*It takes more energy to produce light at the \_\_\_\_\_ end of the spectrum than it does to produce light at the \_\_\_\_\_ end of the spectrum.*

b) Now step out of the laser beams, and make sure they are still striking the light bulb. Look at the lamp through the grating again. You’ll see the laser light spectrum on top of the continuous spectrum from the white-hot filament.

How does laser light differ from that of the incandescent lamp?

Laser light is often described as “**monochromatic**”. Based on what you’ve seen in this activity, what do you think **monochromatic** means?

Can you think of something that produces the sound equivalent of “monochromatic”, that is, it only has one frequency? Remember what you tried out in last week’s lab.

### 9) Light from warm objects.

All objects emit light. As an object gets hotter, it emits more light and it emits light of higher energy (thus higher frequency and shorter wavelength). Warm objects emit mostly infrared light, IR, which we can't see, but this special camera can 'see' infrared light!

Use the camera and your eyes to answer the following questions:

- Which emits more IR light – your eyes, or your nose? Why?
- Look at a cup of hot water vs a cup of cold water. Which one emits more infrared light?
- If we heat something until it gets really hot, do you think it could emit visible light?
- Look at the wire coil in the camera. Tap your foot quickly on the switch.  
What do you see?  
Now hold down the switch and let the coil get hot. Does it emit visible light? \_\_\_\_\_  
What color does it emit? \_\_\_\_\_ Is it still emitting infrared light as well? \_\_\_\_\_
- If we heat up something even more, what will happen to the wavelengths of light it emits?  
Use the light bulb filament. Turn up the voltage on the light filament and describe how its light changes.
- While you have the camera available, see if IR light passes through these materials.  
Predict first!

|                     |              | clear acrylic | glass | black plastic | balloon |
|---------------------|--------------|---------------|-------|---------------|---------|
| Does IR go through? | Prediction:  | _____         | _____ | _____         | _____   |
|                     | Test result: | _____         | _____ | _____         | _____   |