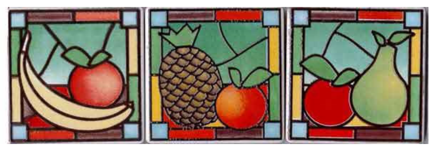
Grades 3 - 5

Digging Deep into Science Literacy

ACTIVITY: Color

Purpose

The normal human eye can perceive a whole rainbow of colors, yet the Sun and most light sources we are familiar with in everyday life produce light that seems to us to be white. Of course, we also see colored lights, for example in fountains, traffic lights, at dances, in theaters, etc. Is colored light completely different from white light, or are they connected in some way?



Many interesting color lighting effects, especially those in live theatrical productions, depend on the use of transparent colored plastic materials called **gels**. Stained glass windows use transparent colored glass to produce their visual effects. Most colored objects we see around us, however, are opaque, not transparent. How do we see them?

In this activity, you will explore these questions. The key questions for this activity are:

> ***1. How do we see colored lights?***
> ***2. How do we see colored objects?***

Initial Ideas

Your instructor will project red and green colored lights on a white wall (or screen). Now suppose your instructor were to move the lights so that they partially overlap on the screen.

What color do you think you would see in the region where they overlap? Why do you think so?

Participate in a discussion. Make a note of any ideas or reasoning that are different from yours.

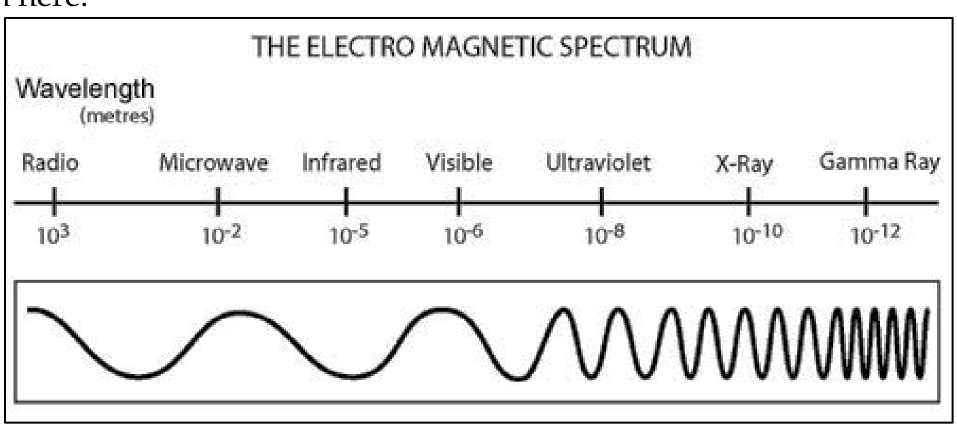
Following the discussion your instructor will overlap the red and green lights.

What color do you see in the region of overlap? Is this what you predicted?

Light as an Electromagnetic Wave

As you may be aware, light is a type of wave. You may have studied some types of wave in a previous unit of this course. Those were called mechanical waves because they need a medium (some type of material, such as a string, water, or even the air) to move through. However, light waves do not need a medium to move through.

When electric charges oscillate, they create disturbances in the electric and magnetic fields around them. These fields exist throughout the whole universe within all materials, and even in the vacuum of space. The disturbances created by oscillating charges move away from the source (oscillating charge) as ***electromagnetic (EM) waves***. Depending on the details of how the oscillating charges move, these EM waves can have any wavelength. Together, all the different types of EM waves form what we call *the electromagnetic spectrum*, with a continuous range of wavelengths from many meters (radio waves) to less than a trillionth of a meter (gamma-rays). What we call visible light is actually only a small part of the complete EM spectrum as shown here.



Collecting and Interpreting Evidence

Each group will need

- Envelope with three color gels (red, green, blue)
- Two flashlights with narrow beams
- Tubular bulb in socket
- Spectral glasses (one pair per person)
- Computer with internet connection
- Second envelope with three different color gels (yellow, cyan, magenta)

Exploration #1: How do we see colored lights?

STEP 1. Turn on your flashlights and (if possible) focus each of them so they produce a small, bright, white spot when shone on a sheet of white paper. Now hold the red gel over one flashlight and the green gel over the other one, and shine them onto the paper from the same distance.

What color do you see where the red and green lights overlap? (This should be close to the same as your instructor's demonstration.)

What color do you think you would see if you overlapped red and blue spots of light? What about blue and green?

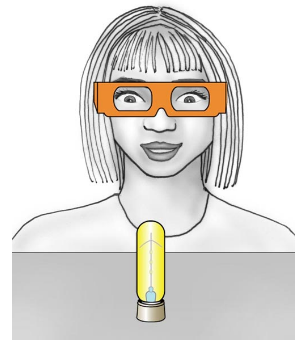
***Prediction*:**

Red **+ B**lue **=**

Blue **+ G**reen **=**

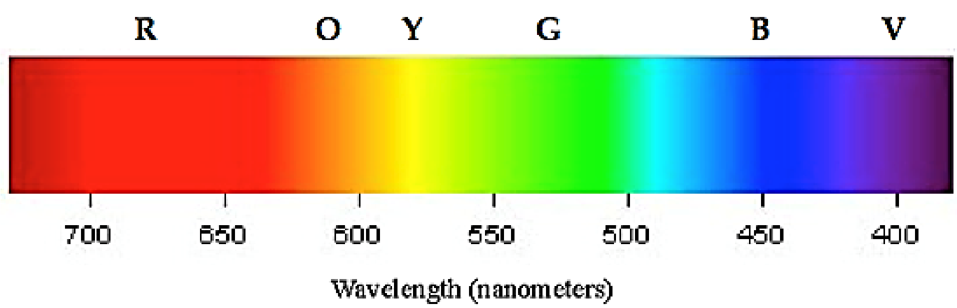
Now use the appropriate color gels to check your predictions. Do your observations match your predictions? If not, describe what colors you do see.

STEP 2. We will now try to understand these results. Plug in and turn on the light bulb. It should look something close to white in color to you. Now look at it through your *spectral* glasses. You should see many bands of colors. The range of colors that you see is called the color ***spectrum*** of the white light source. (The glasses act a like prism to create a spectrum from the white light coming from the bulb.)

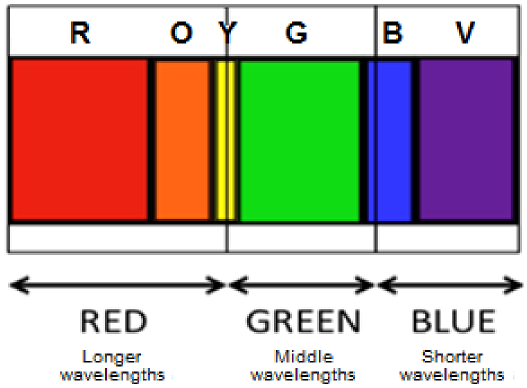


Concentrate on the band that seems to spread out to the immediate **left** from the light source. You should see the familiar 'rainbow', the colors of which are sometimes simply referred to as **ROYGBV**. (Red, Orange, Yellow, Green, Blue, Violet)

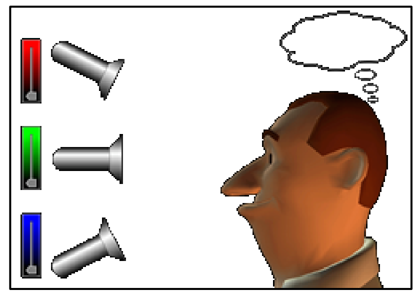
You are seeing this spectrum because the human eye is sensitive to the wavelengths of the electromagnetic spectrum between about 380 nm (perceived as violet light) and 730 nm (perceived as red light). (1 nm = 1 x 10^{-9} m.)



A normal human eye has three different types of color sensitive receptors (called '*cones*') in it that are sensitive to different regions of this color spectrum. One type is sensitive to the red, orange, and yellow region of the spectrum. A second type is sensitive to the middle regions (yellow, green and a little of the blue region). The third type is sensitive to the blue and violet regions. Though there is some overlap of these regions of sensitivity, it is convenient to divide the entire color spectrum into three broad bands, which we will call red (**R**), green (**G**) and blue (**B**), as shown on the next page.



STEP 3. Let us now try to understand how normal color vision works using these ideas and a simulator. Open *PhET Color and Vision* **simulator**, where you will see a man facing red, green, and blue lights, each with dimmer controls attached. Slide the dimmer control on the red light up to its highest setting.



There should currently be a stream of photons[1] from the long wavelength (**R**) band of visible light entering the person's eyes. His (and hence our own) eye-brain system 'perceives' this as 'red light' because this wavelength band mostly 'triggers' only the '**R**' receptors in our eyes. Similarly, light from the middle range of wavelengths triggers our '**G**' receptors and light from the shortest range of wavelengths triggers our '**B**' receptors.

? Suppose equal intensities of light from both the long wavelength band (**R**) and the middle wavelength band (**G**) simultaneously enter our eyes. What color do you think we would perceive and why?

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[1] In this simulation, the light is represented as tiny particles rather than as waves. Although we will not explore that model further, scientists often think of light as consisting of a stream of particles called *photons*. In the simulation, the 'particles' are colored as red, green or blue. The coloring is only a simulator representation to help you keep track of which wavelength band the particles are from; in actual fact, the particles of light are not 'colored.'

Check your thinking by setting both the red and green lights in the simulator to the highest setting. What color is perceived? Is this what you predicted?

Next, check what color is perceived when equal intensities of red light and blue light enter the eye, and then when green light and blue light enter the eye.

What color is perceived when equal intensities of red and blue lights enter the eye?

What color is perceived when equal intensities of green and blue lights enter the eye?

To ensure consistency, we will use the name '***CYAN***' for the mixture of blue and green, and the name '***MAGENTA***' for the mixture of red and blue.

?Now **predict** what you think would be perceived when equal intensities of red, green, **and** blue light enter the eye? Explain your thinking.

Before you check with the simulator, borrow a flashlight from another group and try it yourself.

What 'color' do you see when red, green, and blue light overlap? Is this confirmed by the simulator? Is it what you predicted?

Why does this result make sense in terms of which color receptors are being triggered in your eyes?

We can summarize the simple rules for mixing equal intensities of color lights as follows. We will use the shorthand notation, **R**, **G**, **B**, **W**, **Y**, **C** and **M** to represent red, green, blue, white, cyan (blue-green) and magenta (red-blue) light respectively.

R + G = Y	**R + B = M**	**G + B = C**
	R + G + B = W	

We can perceive other color lights (e.g. orange, lime green, etc.) by mixing different intensities (brightnesses) of **R**, **G** and **B** lights. Try it now with the simulator. This process is known as ***color addition***.

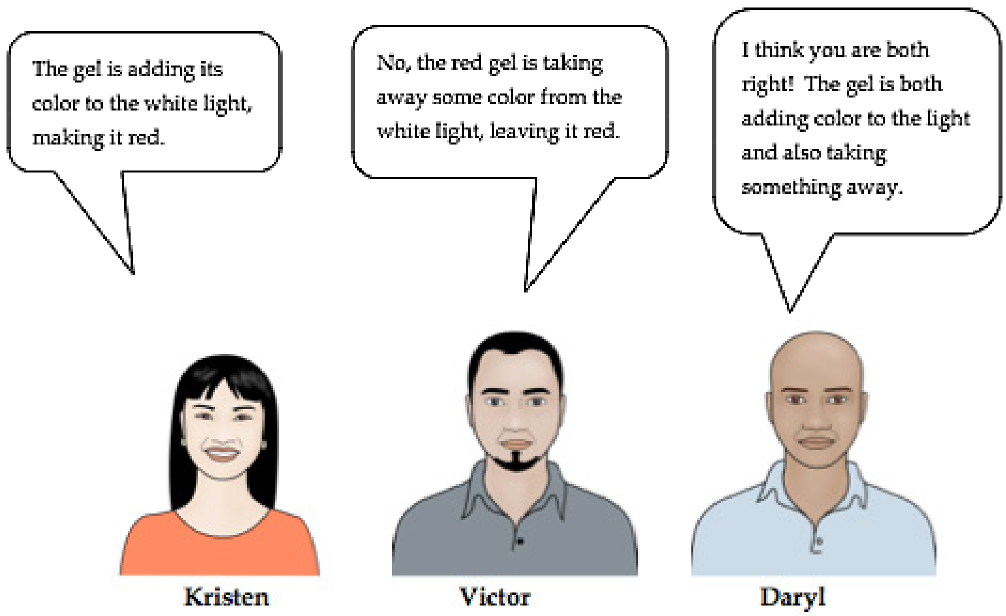
Finally, check what color is perceived when **<u>no light of any color</u>** enters the eye. Why does this make sense?

Lots of devices rely on color addition to produce a seemingly wide range of colors from just red, green, and blue. If you look very closely (with a magnifier) at a computer monitor or a TV screen, you will notice a large number of very tiny and closely spaced dots or stripes of red, green and blue. When viewed from far enough away, the visual effects of tiny, closely spaced dots or stripes are similar to overlapping color lights. Thus, if a region on the screen has brightly glowing red and green dots/stripes, but the blue dots/stripes are turned off, then beyond a certain distance away that part of the screen will appear to a viewer to be yellow in color. The Pointillist artists of the 19^{th} century, the most famous being Georges Seurat, used a similar technique with small, closely spaced dots of color paint. To see the effects they wanted, you need to stand far enough back from the painting so your eye no longer detects the individual dots, but instead sees the additive combination of the colored dots of paint.

Exploration #2: How do color gels work?

STEP 1. In Exploration #1, you produced colored light by placing a color gel over a flashlight, the light from which normally looks white. We will now consider how color gels work to make colored light from white light. Assuming the lights in your room are white, hold the **red** gel up to your eye and look at the lights through the **red** gel. They should appear red to you.

Three students are discussing what the **red** gel is doing to the light.

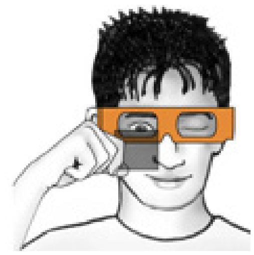


? Which student do you agree with and why?

STEP 2. To find out what a color gel does, you will make some observations using the spectral glasses and a light bulb with a long straight filament.

Each member of your group should make the following observation. Put on your spectral glasses and look at the glowing bulb. Focus on the color spectrum that appears to the **LEFT** of the bulb filament itself. Close one eye and slowly move one of the gels (any color) in front of the other (open) eye.

To see what the gel does, you need to compare what the spectrum looks like both **with** and **without** the gel in front of your eye. To do this, you should hold the gel in a position such that it is covering only the bottom half of the full color spectrum you are seeing. (Alternatively, you could move the gel completely in front of and then away from your open eye several times.)



Based on your observation, does the gel you are using seem to ***add*** its color to the light (in which case certain colors would be brighter when seen through the gel), ***take away*** some colors from the spectrum (certain colors would be dimmer or disappear completely), or ***both*** add and take away?

STEP 3. Now you'll do a more careful set of observations. As you have now seen, the color gels seem to remove certain colors from the spectrum, and we will now determine what these are for each color gel. To make the observations and analyses simpler, we will assume that the full color spectrum is made up of only the three broad bands mentioned earlier: **red (R), green (G), and blue (B)**, and determine which of these three bands each gel removes[2] from the white light and which it 'lets through'.

For example, when you look at the spectrum through the red gel, you should see that the **R** band looks about the same both ***with*** and ***without*** the gel. This means that the **R** band is let through (***transmitted***) by the red gel. However, you should also see that, when viewed through the red gel, most of the **B** and **G** bands are missing (or at least are significantly dimmer). This means that the **B** and **G** bands are removed (***absorbed***) by the red gel.

NOTE: *These gels are not perfect and so in some cases, you may see a little of the other bands, but at least some parts of one or more bands should be removed, or be somewhat dimmer than they are without the gel.*

[2] When we say the a color gel 'removes' one or more color bands from the light, what actually happens is that inside the gel there is a chemical dye that has the property of absorbing a particular band or bands of light.

Make observations with your spectral glasses and gels to complete the table below according to which of the **R**, **G**, and **B** bands each gel seems to remove (absorbed) and which it lets through (transmitted). The first line has been done for you.

Remember to make allowances for the fact that the gels are not perfect!

Table 1: Which color bands of the spectrum do each of the gels seem to remove and which do they let through?

Name of gel	Which color band(s) are ***removed (absorbed)***? Choose from R, G and/or B	Which color band(s) are ***let through (transmitted)***? Choose from R, G and/or B
Red	**G B**	**R**
Green		
Blue		
Yellow		
Cyan		
Magenta		

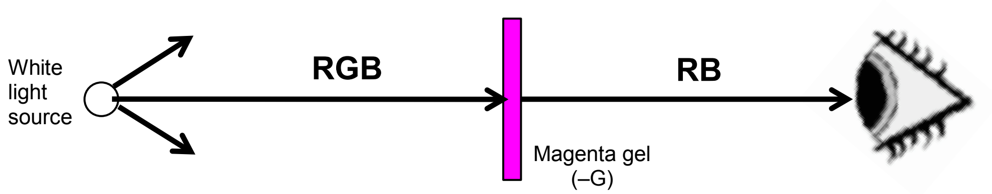
Recall from Exploration #1 that when red, green, and blue light enter the eye, it is seen as white light. So when we look at the white light source without the spectral glasses, we can imagine that all three of the red, green and blue bands of the spectrum are entering our eyes.

Why do we see green when we look at a white light source through a green gel?

Why do we see magenta when we look at a white light source through a magenta gel?

STEP 4. Sometimes it is convenient to label a color gel by what components it ***removes*** from the white light. For example, a red (**R**) gel could also be called a −**G** −**B** gel (minus **G**, minus **B**), and a magenta (**M**) gel is a −**G** gel (minus green), and so forth. Another name for a color gel is a **color filter,** which already suggests that it removes something from the light. When we use gels or dyes to remove colors from light, we call it ***color subtraction***.

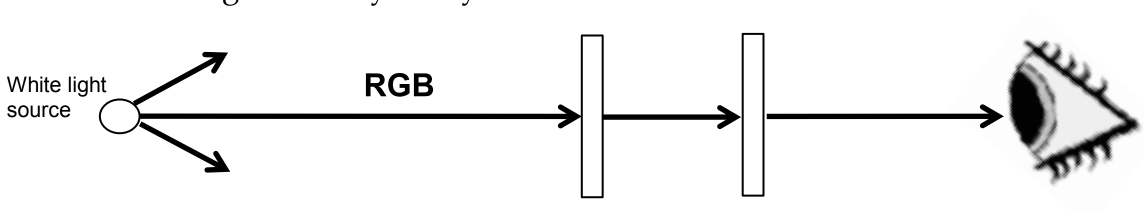
We can add information about color to a light ray diagram to help us when working with the ideas of color subtraction. For example, a diagram for a person looking at a white light through a magenta gel would look like this.



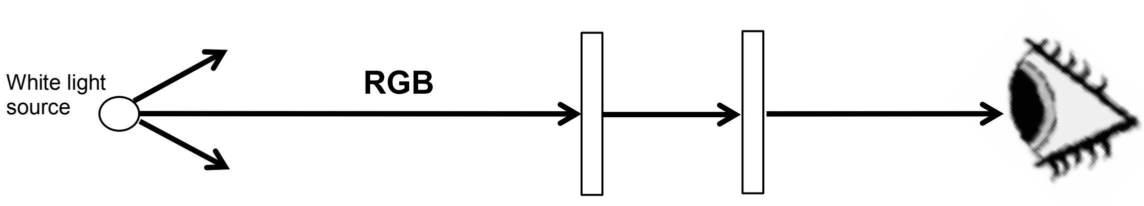
The light being emitted by the source is white, so it contains all three of our color bands (**R**, **G**, **B**). A magenta gel can be regarded as a –**G** filter and so it removes the **G** band from the white light, leaving the **R** and **B** bands to enter the eye. As you saw in Exploration #1, we perceive this particular combination of bands as magenta.

To check your understanding of these ideas, consider the following questions. ***Be sure to make your predictions before trying the experiments!***

Suppose you overlapped a cyan (**C**) gel and a green (**G**) gel and looked at the white room lights through them both ***without*** using the spectral glasses! Predict what color you would see. To help, draw a color light ray diagram that shows white light passing first through a cyan gel and then through a green gel before the light enters your eye.



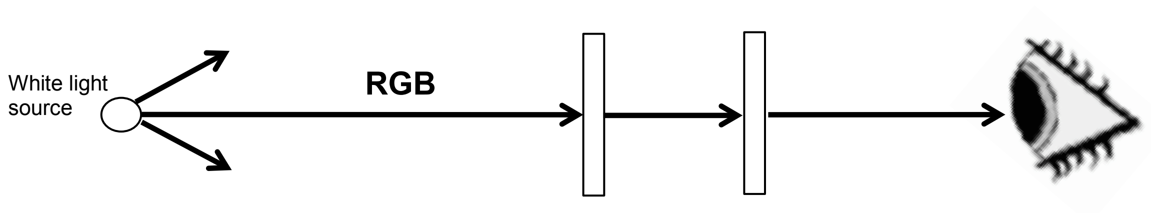
Would it matter whether the white light passed through the cyan or the green gel first? (If you are not sure, draw another diagram with the order of the gels switched.)



DO NOT USE THE SPECTRAL GLASSES!

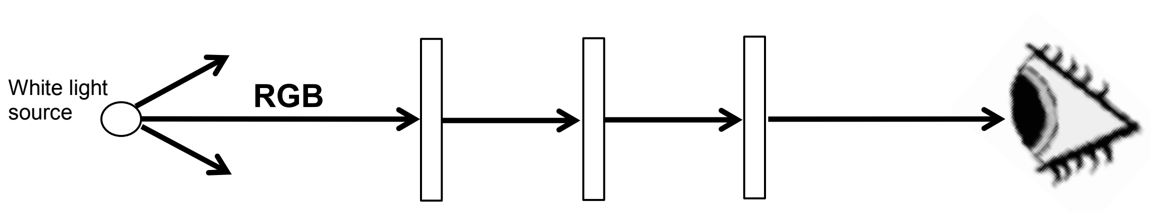
Try it now. What color do you see when looking at the white room lights through overlapping cyan and green gels? If this is not what you predicted, try to explain it.

Now, suppose you looked at the room lights through a combination of overlapping yellow and magenta gels. Draw a color light ray diagram to help you predict what color you would you expect to see.



Try it now. What color do you see? If this is not what you predicted, try to explain it.

Finally suppose you looked at the room lights through a combination of yellow, cyan, and magenta gels. What color (if any) would you expect to see and why?



Try it now. What color do you see? If this is not what you predicted, try to explain it.

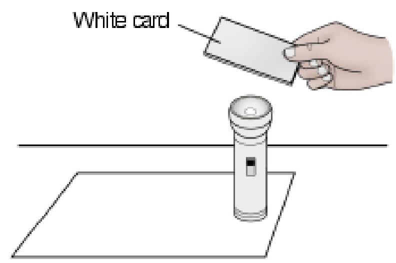
Exploration #3: How do we see colored objects?

STEP 1. Consider looking at a piece of red paper being illuminated by a white light source.

Why do you think the paper looks red to you?

STEP 2. Before we explore how we see colored objects, let us first remind ourselves what happens when light hits a non-shiny object.

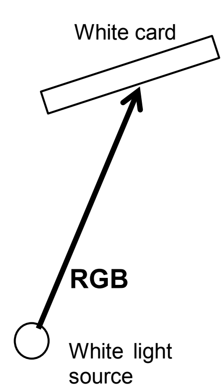
Turn on the flashlight and stand it upright at one end of the paper. Hold the white card as shown in the picture, so the flashlight beam strikes the card. Move the card in and out of the beam of light and observe what happens on the sheet of paper.



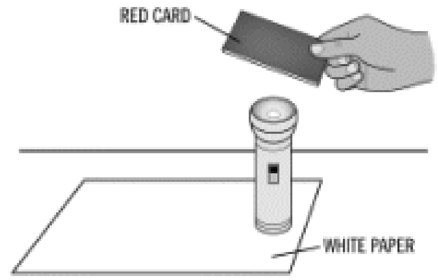
Is light being reflected from the card and, if so, what color is that light? How do you know?

The light hitting the card (from the flashlight) is white, which we can regard as a combination of the **R**, **G**, and **B** color bands. What color bands are being reflected from the white card? How do you know?

Complete this color light ray diagram to show your thinking. ***Be sure to show in what direction(s) you think the light is reflecting and what color bands are in the reflected light.***

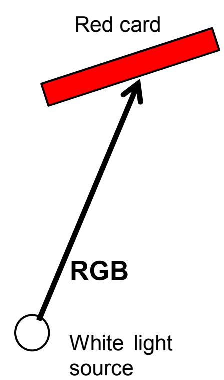


Now repeat the experiment using the **red** card instead of the white card. While looking at the white paper, move the **red** card in and out of the flashlight beam.



Is light being reflected from the card and, if so, what color is that light? How do you know?

What color bands are being reflected from the red card and which are being absorbed? How do you know? Complete the color light ray diagram to show your thinking.

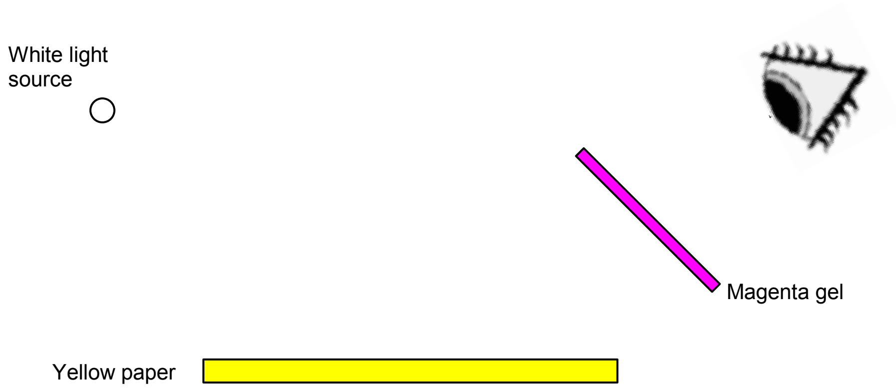


As you have probably deduced, the dye in the red card absorbs the green and blue bands of light and reflect the red band. In this sense, the way light is reflected or absorbed by a colored object is the same as the way it is transmitted or absorbed by a colored gel.

Use these ideas to explain why a yellow piece of paper appears yellow when illuminated by a white light source.

STEP 3. Now consider a different situation.

Suppose a yellow colored object was to be illuminated by a white light but you then looked at it through a magenta gel. Assuming there are no other light sources around, what color would the yellow object look to you? Draw a color light ray diagram below to show your thinking.



Check your thinking by laying a yellow gel on white paper and looking at it through a magenta gel. Is the color you see at least close to what you predicted? (Remember, the gels are not ideal.) If not, try to explain what you do see.

Summarizing Questions

S1: A TV nature program shows a close up of an exotic bird that has areas of green, cyan, and magenta plumage (feathers). If you were to look closely at each of these areas on the TV screen, which dots/stripes would you expect to be lit up brightly? Explain your thinking.

S2: You look at a white light source through the overlapping combinations of color gels below. Assuming the gels are ideal, in each case what color would you expect to see and why?

a) Blue and Magenta

b) Magenta and Cyan

c) Red and Cyan

S3: In a theatrical production, a certain actor is wearing a costume that appears yellow when white light shines on it. For dramatic effect the producer wants the audience to perceive a quick change in the costume from yellow to black. How could the lighting director achieve this effect by placing a colored gel in front of the white spotlight illuminating the actor? (**NOTE**: *He cannot turn the spotlight off or block it off because the actor's face must still be visible*.)

Construct an explanation for how this effect can be achieved. Draw two color light ray diagrams to show how the audience perceives the costume first as yellow and then as black. Also, write a few sentences to explain your diagrams.