# COLOR PHENOMENA

## INTRODUCTION

Vision is arguably our most compelling sense. ("Seeing is believing.") Although we can easily interpret colorless images (black-and-white photographs, paths through the woods on a moonlit night, etc.), we tend to find images in color far more interesting and informative.

In one important way, however, our color vision is impoverished relative to other senses. When we taste a solution of sugar and salt, we experience both sensations (sweet and salty), and not some "average." But when we observe mixtures of paints of different colors, we experience a color different from the constituent colors. This happens for lights, as well. Often, more than one combination of pigments or lights can yield a single color sensation. We will begin to explore this phenomenon in lab this week

### *Some useful concepts*

**Hue:** Main color (e.g., red, orange, yellow, etc.).

**Brightness:** The overall intensity of the light from dark to dazzling, or the total amount of light.

**Saturation:** The purity of a color. The absence of other colors of the spectrum that would combine to make white (or gray), therefore the degree of difference of a hue from gray (or white) of the same brightness. Red is saturated, pink is unsaturated. (Notice that this is unrelated to brightness.)

**Additive color mixing:** Mixing lights of different colors so you see them in a single spot simultaneously. The lights are *added* together.

**Subtractive color mixing:** Combining the filters through which one light shines (or the pigments off which one light reflects). Each filter *subtracts* part of the light.

**Resolving power:** The minimum distance between two objects necessary for a lens to distinguish (*resolve*) them as distinct objects. [This is a useful idea when you consider color printing and TV screens.] The resolving power of the human retina is a little less than a tenth of a degree.

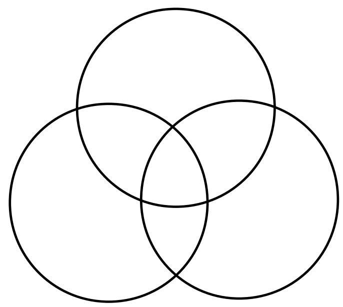
### *Distinguishing colors.*

We can distinguish about 20 steps of saturation for a given wavelength of light, and about 500 steps of brightness for every hue and grade of saturation. A totally color-blind person (like the colorblind painter) can also distinguish levels of brightness but not differences in hue or saturation. Thus, a totally color-blind person can distinguish about 500 grades of brightness in differentiating an object from the background. In contrast, a person with normal color vision can distinguish 200 hues X 20 grades of saturation X 500 steps of brightness = 2 million gradations of hue, saturation and brightness combined! (Is this how many colors there are? Can we distinguish this many? Can we name them all?)

## PART 1: BASIC COLOR THEORY

### *Additive color mixing with light sticks*

Try to come up with a set of rules for mixing red, green, and blue light, in pairs and all together. Use the light sticks provided, and shine the lights onto a white surface, overlapping them as appropriate, and fill out the table below with the algebra of additive color mixing.



| | |
|---|---|
| R + G = | |
| R + B = | |
| G + B = | |
| R + G + B = | |

### Additive color mixing on the computer screen

Open the image called additive_color_mixing.png, either on your phone, or on a computer.

If you are using your phone or a tablet, put it under a dissecting microscope so you can look at it magnified.

If you are using a computer, take an ocular from a microscope and look at the screen through it wrong way round (i.e., put the lens that is usually closest to your eye to the screen and look through the other end.).

How does the display work? Does it follow the rules?

✓ **Be sure you are clear on why this is called additive mixing, and why R, G, and B are the additive primary colors, and why C, Y, and M are the additive secondary colors.**

## *Subtractive Color mixing*

### with filtered light

Solve these problems by algebra, writing each statement first in terms of the additive primary colors, then in terms of the additive secondary colors. Then test the truth of them by clever placement of filters on the overhead projector, or on the glass plate on the dissecting scope. (Which colors can pass through the C, Y, or M filters, and which cannot?)

| | Additive primaries | Additive secondaries |
|---|---|---|
| W - R = | | = |
| W - G = | | = |
| W - B = | | = |

Demonstrate these results by making a three color spot of white on the screen with the light sticks, and making shadows.

Solve these problems with algebra.

| | |
|---|---|
| W - C = | |
| W - M = | |
| W - Y = | |

If you take all the colors away from white light, you have no more light, also known as black (abbreviated K). Demonstrate this with clever placement of filters.

W - R - G - B = K

Solve these problems by algebra

| | |
|---|---|
| K = W - R - | |
| K = W - G - | |
| K = W - B - | |

✓ **Be sure you are clear on why this is called subtractive mixing, and why C, Y, and M are the subtractive primary colors.**

## Subtractive color mixing on the printed page

What colors of ink does the standard color printer use?

You can see what we use in the Xerox ColorQube printers in ISB by opening the file called xerox_color_ink.png

Find examples of images printed in the following colors, and examine them to see how they are created on the page. Then explain how this works by color algebra

| Color on page | Inks used | Color algebra explanation |
|---|---|---|
| R | | |
| G | | |
| B | | |

## Orange

What is orange?

How is it made on the computer screen?

How is it made on the printed page?

# PART 2: WHAT'S WHERE ON YOUR RETINA

## *Resolving Power*

The resolving power of any detecting device is its ability to distinguish two stimuli from one.

In any sensory system in the nervous system of an animal, resolving power depends on the size of the receptive field that reports to a single neuron. Sense organs are usually divided into overlapping receptive fields, so that stimulating a particular spot on the surface (of the skin, or retina, for example) actually sends signals to more than one neuron. Comparing the responses of all the neurons gives information about the number, size, and location of stimuli.

The key to resolving two stimuli is to have an unstimulated receptive field between two stimulated ones. Some pairs of stimuli are indistinguishable from a single stimulus. As shown in Figure 1, a single stimulus, A, that falls in two receptive fields (as all stimuli do, since the fields overlap) will produce the same response as two stimuli, B and C, if these stimulate the same two receptive fields. In other words, the two stimuli cannot be resolved. Two stimuli (D and E) that affect two receptive fields separated by an unstimulated field, however, produce a different signal, and the organism can resolve the two. The smallest distance between two stimuli that can be resolved gives us an indication of the size of the receptive fields.

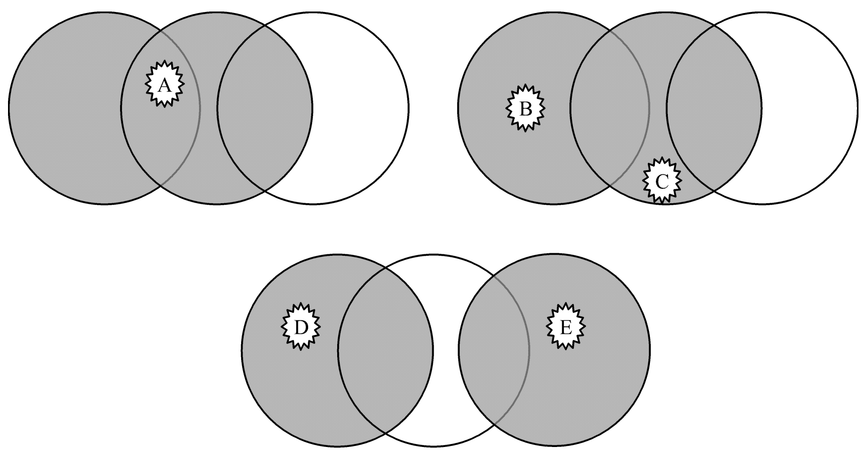



**Figure 1. Three different placements of stimuli in three receptive fields.**

The surface of your retina is divided into receptive fields, just as your skin is. The individual photoreceptive cells report as part of a group to a bipolar cell in the next layer of the retina, and that bipolar cell reports to a ganglion cell. Each photoreceptor belongs to more than one such receptive field, so the fields overlap, just as they do on your skin.

A picture will be hung on one wall of the room that is similar to the one below. Stand as far away from the picture as you can, then walk toward it. Stop when you can tell which of the gray bars is actually two black lines with a 1 mm white space between them. Measure your distance from the wall.

## *The Fovea*

The very central region of the retina is called the fovea. This is the region where your color vision is most acute. The entire image of a small or distant object can fit entirely in your fovea.

### Where is our sharpest vision?

Stare at the circle in the middle of this line ° and see whether you can read the words at the margins without moving your eyes. If you can, try the same exercise with a larger piece of written material. (E.g., stare at the gutter in the middle of an open book and try to read the text at the outer margins.)

### How big are foveal receptive fields?

Walk toward or back away from the lines display until the you cannot distinguish between single and double lines.

### Are the red, green, and blue cones equally represented in the fovea?

Have your buddy hang (or hold) the yellow card with 4 dots on it at eye level somewhere (like at the end of a well-lit hallway) where you can stand 20 or 30 feet away from it, then walk toward it. From across the room, the image of each dot is quite small, and it falls entirely on the fovea. As you get closer to the card, the image takes up a larger and larger portion of your retina. Monitor the colors of the dots as you walk slowly to or from the cards. (If you see nothing change, try the other size dots.)

Are all colors equally detectable at all distances? What can you conclude about the relative numbers of R, G, and B cones in the fovea? (Remember that the designations R, G, and B refer to the type of light absorbed.)

### Where on our retina are our cone cells found?

Ophthalmologists use a device for mapping the retina called a **visual field perimeter.** The subject sits at the center of a hemisphere, along whose various circumferences tiny red, green, blue, or white lights can be blinked. From the subject's responses (seeing something, knowing its color), the technician constructs a map of the retina. We will use the basic idea behind the perimeter, without measuring the actual angles.

Work with a buddy. Find a place with uniform, not too bright lighting (not facing a desk lamp or a window in daytime). Sit or stand where you have room to spread both arms. Find a point to stare at. (Pick something small and distinct.) To do this properly, you must absolutely keep your eyes on this point! You will not experience the effect if you turn your eyes or head!

Close or cover one eye. Stare at your spot with the open eye. Extend your arm on that side straight out from the shoulder. You shouldn't be able to see it, even if you wiggle your fingers. Slowly bring your outstretched arm toward the front, keeping it parallel to the floor, while you wiggle your fingers. (Don't cheat! Stare at your spot!) At some point, you will be able to detect the movement. This gives you a sense of the extent of your visual field.

Here's where the buddy comes in. Hold your arm out to your side, as before. Have your buddy put a card in your hand, without telling you what color dot is on it. Wiggle the card slightly as you slowly bring your arm toward the front. (Stare straight ahead! Don't move your eyes!) When do you know what color it is? The color may go away if you stop wiggling the card. Have your buddy make estimates of the angle (or mark the floor directly below your hand).

Repeat this for the other cards. Your buddy should hand you the same card more than once, so anticipation won't influence your perception (e.g., "The only one I haven't seen is blue, so this must be blue!"). This gives you a sense of the extent of your color vision.

Repeat one last time, with the card that has all the dots. Be honest, now. Are all the colors detectable at the same angle? Which do you see furthest out in the periphery? Which needs to be closest to the middle of your visual field?

Switch roles, and let your buddy investigate her peripheral vision.

What can you conclude about the distributions of the red, green, and blue cone cells (named not for the color they appear, but the type of light they absorb) on the retina from these observations?

## *Find your blind spot*

You may have found a location during the previous exercise where the dot disappears altogether. This is your blind spot. To demonstrate this phenomenon more clearly, follow the instructions below.

Cover your left eye and look at the diagram below with your right eye. Hold the paper at arm's length and stare at the dot on the left, but pay attention to the cat on the right. Slowly bring the paper toward you, and note what happens to the cat. (You may test your left eye, too, by turning the paper upside down.) What anatomical feature of your eye causes this (see below)?

## *See the pattern of blood vessels*

The retina is nourished via the circulatory system. With some patience, you can see the network of blood vessels, all leading to the optic nerve, where they exit the eye. Close your eyes, and hold a penlight just above your closed eyelid, on the temporal side, and wiggle the light back and forth slightly. The vessels cast visible shadows in a branching pattern, leading to a point of origin just off center. There are no vessels in your fovea.

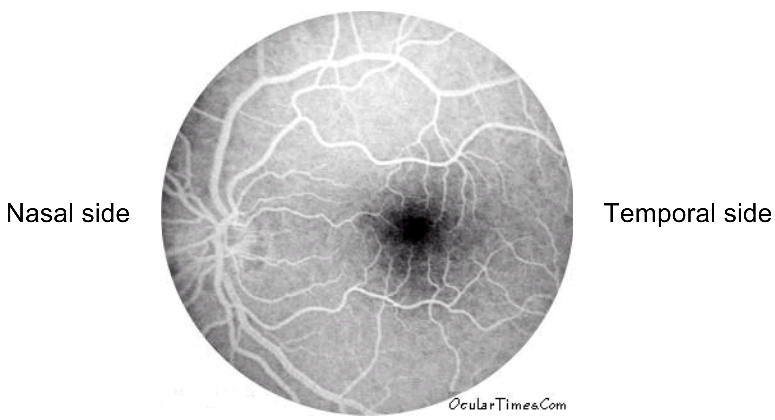
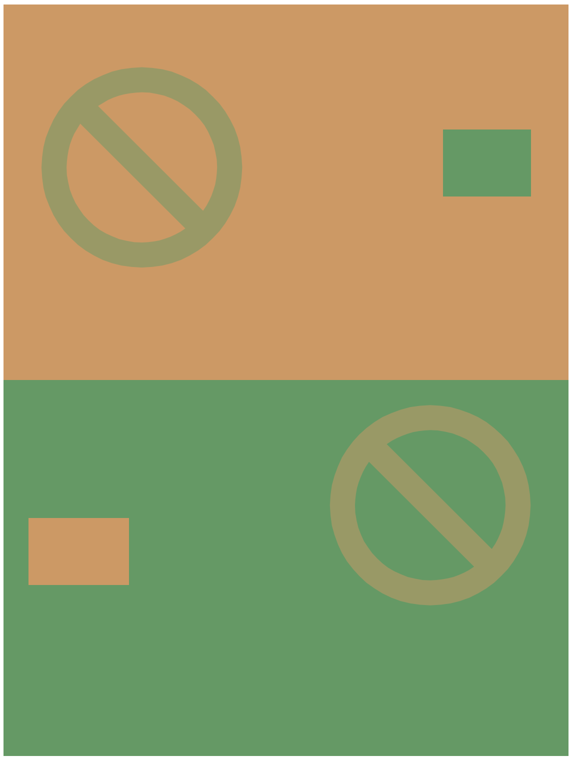



**Figure 2. Photo of a normal fluorescein pattern on the retina of a left eye, as seen by looking into the eye through the pupil. The network of blood vessels is white, and the fovea, which has no vessels blocking it, is dark.**
**(from Ocular Times.com http://www.geocities.com/ocular_times/fa.html)**

## WOULD THAT IT WAS THAT SIMPLE: COLOR OPPONENCY

Examine this image on a computer screen. Select each object and find its RGB settings, then explain what you see as a function of the relative amounts of each color.



## YOUR REPORT:

Answer each of the following questions, and ***provide specific supporting evidence from this exercise***.

**1.** Color Theory
- Explain the basic theory of color mixing, using algebraic notation.
- Why does a three-color system work for printing and computer screens?

**2.** Color vision. Referring to the demonstrations you have done today, compare the fovea and the periphery of your retina, with respect to:
- the distribution and density of color receptors
- the size of receptive fields.

**3.** Explain the red-green illusion in terms of color mixing.