10.2 Color and Vision

The energy of light explains how different colors are physically different. But it doesn't explain how we *see* colors. How does the human eye see color? The answer explains why computers and TVs can make virtually all colors with combinations of only three colors!

The human eye

Photoreceptors Light enters your eye through the lens then lands on the retina. On the surface of the retina are light-sensitive cells called *photoreceptors* (Figure 10.7). When light hits a photoreceptor cell, the cell releases a chemical signal that travels along the optic nerve to the brain. In the brain, the signal is translated into a perception of color.

Cone cells respond to color

Our eyes have two kinds of photoreceptors, called *cones* and *rods*. *Cones* (or *cone cells*) respond to color (Figure 10.8). There are three types of cone cells. One type responds best to low-energy (red) light. Another type responds best to medium-energy (green) light. The third type responds best to higher-energy (blue) light.

Rod cells respond to light intensity

The second kind of photoreceptors are called *rods* or *rod cells.* Rods respond to differences in light intensity, but not to color (Figure 10.8). Rod cells "see" black, white, and shades of gray. However, rod cells are much more sensitive than cone cells. At night, colors seem washed out because there is not enough light for cone cells to work. When the light level is very dim, you see "black and white" images from your rod cells.

Black and white vision is sharper than color vision

A human eye has about 130 million rod cells and 7 million cone cells. Each cell contributes a "dot" to the image assembled by your brain. Because there are more rod cells, things look sharpest when there is a big difference between light and dark. That's why black and white letters are easier to read than colored letters. Each cone cell "colors" the signals from the surrounding rod cells. Because there are fewer cone cells, our color vision is much less sharp than our black-and white vision.

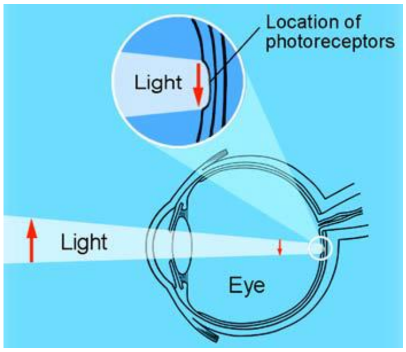

Figure 10.7: *The photoreceptors that send color signals to the brain are in the back of the eye*

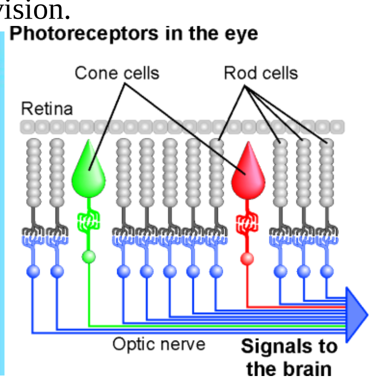

Figure 10.8: *The human eye has two types of photoreceptors—cones and rods. Cones respond to color and rods respond to the intensity of light*

How we see colors

The additive color process

Because there are three kinds of cone cells, our eyes work by adding three signals to “see” different colors. The color you “see” depends on how much energy is received by each of the three different types of cone cells. The brain thinks “green” when there is a strong signal from the green cone cells but no signal from the blue or red cone cells (Figure 10.9).

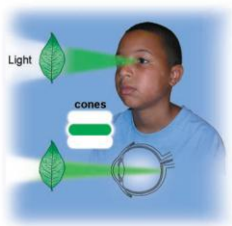

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Figure 10.9: *If the brain gets a signal from only the green cone, we see green.*

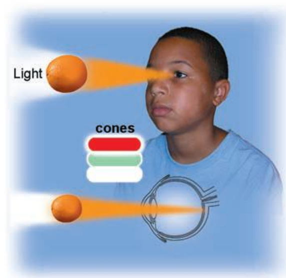
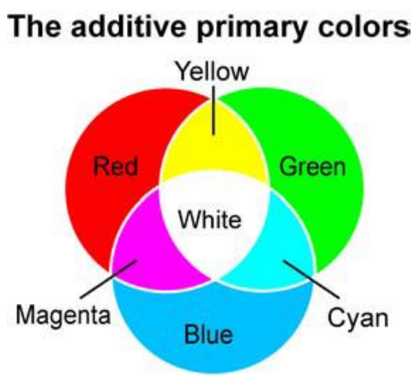


Figure 10.10: *If there is a strong red signal and a weak green signal, we see orange*

How we perceive color

What color would you see if light creates signals from both the green cones and the red cones? If you guessed *yellow*, you are right. We see yellow when the brain sees yellow light or when it gets an equally strong signal from both the red and the green cone cells at the same time. Whether the light is actually yellow, or a combination of red and green, the cones respond the same way and we perceive yellow. If the red signal is stronger than the green signal we see orange (Figure 10.10).



If all three cones send an equal signal to the brain, we see white.

Two ways to see a color

The human eye can be “tricked” into seeing any color by adding different percentages of red, green, and blue. For example, an equal mix of red and green light looks yellow. However, *the light itself is still red and green!* The mix of red and green creates the same response in your cone cells as does true yellow light.

Do animals see colors?

To the best of our knowledge, primates (such as chimpanzees and gorillas) are the only animals with three-color vision similar to that of humans. Some birds and insects can see ultraviolet light which humans cannot see. Dogs, cats, and some squirrels are thought to have only two color photoreceptors. Although both octopi and squid can change color better than any other animal, we believe they cannot detect color with their own eyes!

Making an RGB color image

The RGB color process

Color images in TVs and computers are based on the **RGB color model.** RGB stands for “Red-Green-Blue.” If you look at a TV screen with a magnifying glass, you see thousands of tiny red, green, or blue **pixels** (Figure 10.11). A television makes different colors by lighting red, green, and blue pixels to different percentages. For example, a light brown tone is 88 percent red, 85 percent green, and 70 percent blue. A computer monitor works the same way.

Pixels make up images

TVs, digital cameras, and computers make images from thousands of pixels. An ordinary TV picture is 640 pixels wide × 480 pixels high, for a total of 243,200 pixels. A high-definition picture looks sharper because it contains more pixels. In the 720p format, HDTV images are 1,280 pixels wide × 720 pixels high, for a total of 921,600 pixels. This is four times as sharp as a standard TV image.

Video cameras create color images

Like the rods and cones in your retina, a video camcorder has tiny light sensors on a small chip called a CCD (Charge-Coupled Device). There are three sensors for each pixel of the recorded image, red, green, and blue. In HDTV that means each recorded image contains 921,600 × 3 = 2,764,800 numbers. To create the illusion of motion, the camera records 30 images per second. In terms of data, the HDTV movie you watch represents 2,764,600 × 30, or about 83 million numbers every second!

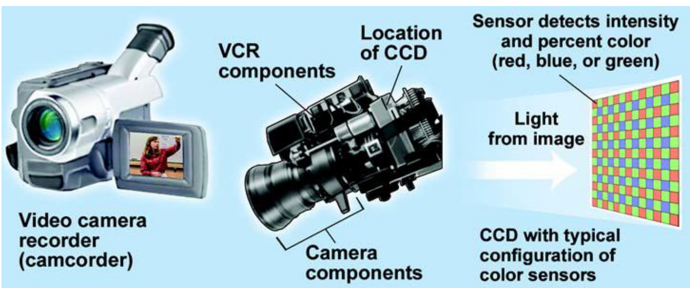


Figure 10.11: *A television makes colors using tiny glowing dots of red, green, and blue.*

How objects appear to be different colors

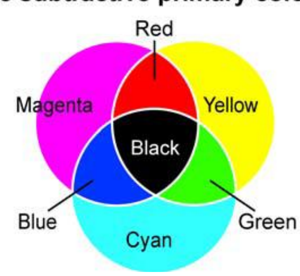
What gives objects their color?

Your eye creates a sense of color by responding to red, green, and blue light. You don't see objects in their own light, you see them in reflected light! A blue shirt looks blue because it *reflects blue light into your eyes* (Figure 10.12). However, the shirt did not *make* the blue light. The color blue is not *in* the cloth! The blue light you see is the blue light mixed into white light that shines on the cloth. You see blue because the other colors in white light have been subtracted out (Figure 10.13).

The subtractive color process

Colored fabrics and paints get color from a *subtractive color process*. Chemicals known as *pigments* in the dyes and paints absorb some colors and reflect other colors. Pigments work by taking away colors from white light, which is a mixture of all the colors.

The subtractive primary colors



The subtractive primary colors

To make all colors by subtraction we need three primary pigments. We need one that absorbs blue (reflects red and green). This pigment is called *yellow*. We need another pigment that absorbs green (reflects red and blue). This is a pink-purple pigment called *magenta*. The third pigment is *cyan*, which absorbs red (reflects green and blue). Cyan is a greenish shade of light blue. Magenta, yellow, and cyan are the three *subtractive primary colors* (see illustration above). Different proportions of the three subtractive primary colors change the amount of reflected red, green, and blue light.

How "white" is white?

A blue shirt won't look blue in red light! It will look *black*! The subtractive color model assumes a painted or dyed surface is seen in white *sunlight* containing a precise mix of colors. If the "white" has a different mix than sunlight, colors don't look right. This is why home videos made under fluorescent lights often look greenish. The white from fluorescent lights has a slightly different mix of colors than the white from sunlight.

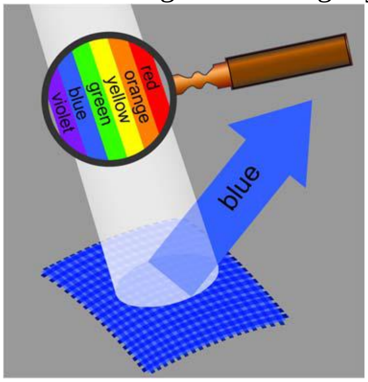


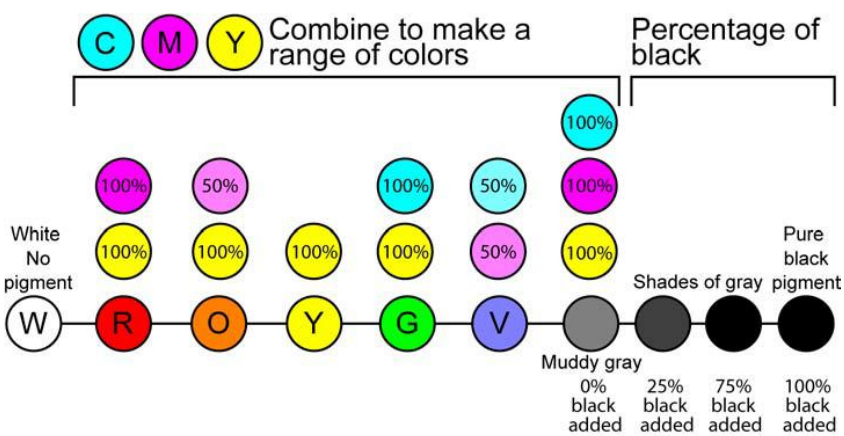
Figure 10.13: *The pigments in a cloth absorb all colors except blue. You see blue because blue light is reflected to your eyes.*

Figure 10.12: *Why is a blue shirt blue?*

The CMYK color process

A subtractive color process

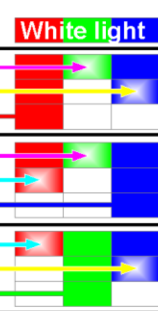
The subtractive color process is often called **CMYK** for the four pigments it uses. CMYK stands for cyan, magenta, yellow, and *black*. The letter K stands for black because the letter B is used for the color blue in RGB. Color printers and photographs use CMYK.



CMYK are pigments

The three pigments, cyan, magenta, and yellow can combine in different proportions to make any color of reflected light. Figure 10.14 shows how CMYK pigments make green. Theoretically, mixing cyan, magenta, and yellow should make black, but in reality the result is only a muddy gray. This is why a fourth color, pure black is included in the CMYK process.

To make	Mix	Because
Red	Magenta and yellow	Magenta absorbs green Yellow absorbs blue Red gets reflected
Blue	Magenta and cyan	Magenta absorbs green Cyan absorbs red Blue gets reflected
Green	Cyan and yellow	Cyan absorbs red Yellow absorbs blue Green gets reflected



Why plants are green

Light is necessary for photosynthesis

Plants absorb energy from light and convert it to chemical energy in the form of sugar. This process is called *photosynthesis*. The vertical (*y*) axis of the graph in Figure 10.15 shows the percentage of different colors of light that are absorbed by a plant. The *x*-axis on the graph shows the colors of light. The graph line shows how much and which colors of visible light are absorbed by plants. Based on this graph, can you explain why plants look green?

Why most plants are green

The important molecule that absorbs light in a plant is called *chlorophyll*. There are several forms of chlorophyll. They absorb mostly blue and red light, and reflect green light. This is why most plants look green. The graph in Figure 10.15 shows that plants absorb red and blue light to grow. A plant will die if placed under only green light!

Plants reflect some light to keep cool

Why don't plants absorb all colors of light? The reason is the same reason you wear light-colored clothes when it is hot outside. Like you, plants must reflect some light to avoid absorbing too much energy and overheating. Plants use visible light because the energy is just enough to change certain chemical bonds, but not enough to completely break them. Ultraviolet light has more energy but would break chemical bonds. Infrared light has too little energy to hange chemical bonds.

Why leaves change color

The leaves of some plants, such as sugar maple trees, turn brilliant red or gold in the fall. Chlorophyll masks other plant pigments during the spring and summer. In the fall, when photosynthesis slows down, chlorophyll breaks down and red, orange, and yellow pigments in the leaves are revealed!

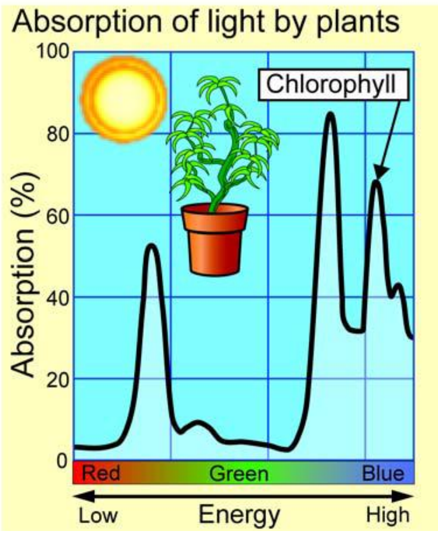


Figure 10.15: *Plants absorb energy from light. The plant pigment chlorophyll absorbs red and blue light, and reflects green light. This is why plants look green!*

10.2 Section Review

1. If humans have only three kinds of color photoreceptors, how can we see so many different colors?

2. Why is it easier to read black and white text compared to green text or text of any light color?

3. Why might it be a good idea to put a light in your clothes closet? (Hint: What kind of vision do we have in dim light?)

4. Do you think this text book was printed using the CMYK color process or the RGB color process? Explain your answer.

5. If you were going to design the lighting for a play, would you need to understand the CMYK color process, the RGB color process, or both? Explain your answer.

6. Suppose you have cyan, magenta, yellow, and black paint. Which colors would you mix to get blue?

7. Why does static on a television set appear white?

8. How is the color black produced in the CMYK color process versus the RGB color process?

9. A red shirt appears red because
a. the shirt emits red light
b. the shirt absorbs red light
c. the shirt emits green and blue light
d. the shirt absorbs green and blue light

10. Some plants that grow in shady areas have dark green or even purple leaves. Come up with a hypothesis to explain this observation.

11. What would happen if you tried to grow a green plant in pure green light? Would the plant live? Explain your answer.

12. Propose an explanation for how the top image in Figure 10.16 is related to the four images below it.