18.4 Color

Reading Focus

Key Concepts

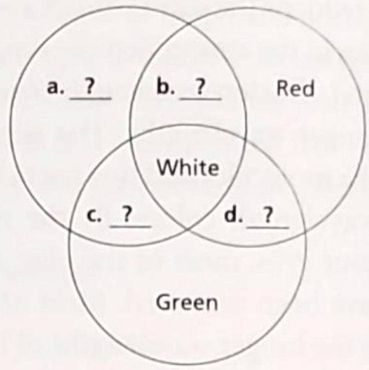
- How does a prism separate white light?
- What determines the color of an object?
- What are the primary colors of light?
- What are the primary colors of pigments?

Vocabulary

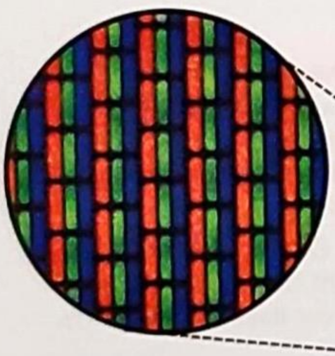
- dispersion
- primary colors
- secondary color
- complementary colors of light
- pigment
- complementary colors of pigments

Reading Strategy

Venn Diagram Copy the Venn diagram below. After you read, label the diagram for mixing primary colors of light. Make a similar diagram for mixing primary colors of pigments.



Have you ever zoomed in on a color photograph displayed on a computer screen? If you have, you've seen that the photograph is made up of many tiny squares, called *pixels,* as shown in Figure 22. Your computer screen might be set to display 256 colors, thousands of colors, or even millions of colors. All of these colors are generated using various combinations of only three colors of light. If you were to print the same photograph, your printer would also use only three colors, plus black, to create the image out of tiny dots of ink. The three colors the computer uses are different from the three the printer uses. How can that be?



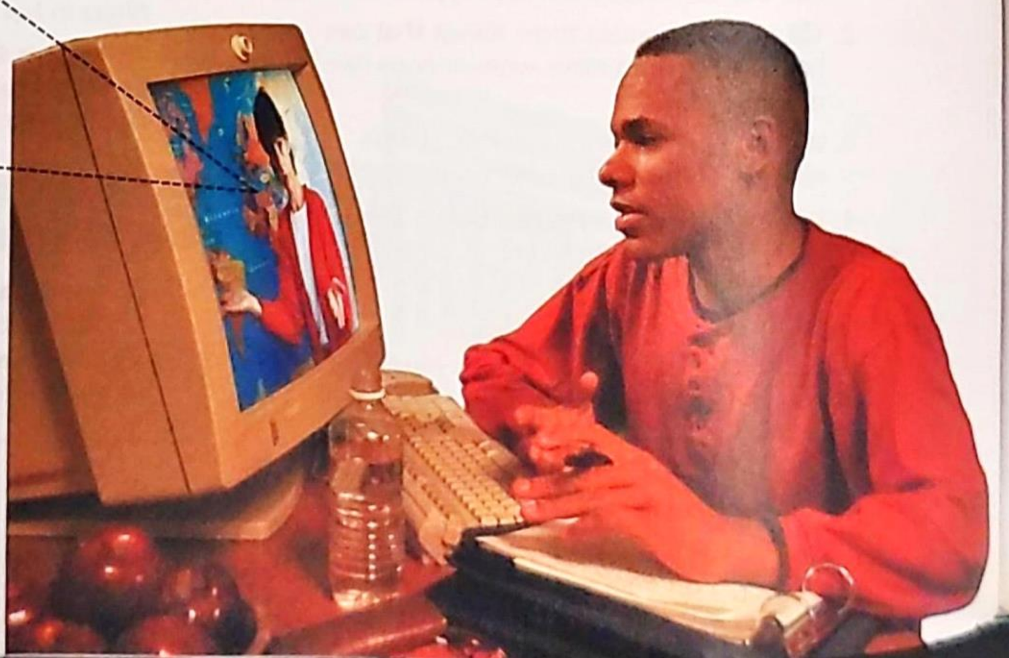


Figure 22 This student is looking at many colors on his computer screen. What he is actually seeing, however, are combinations of only three colors of light.

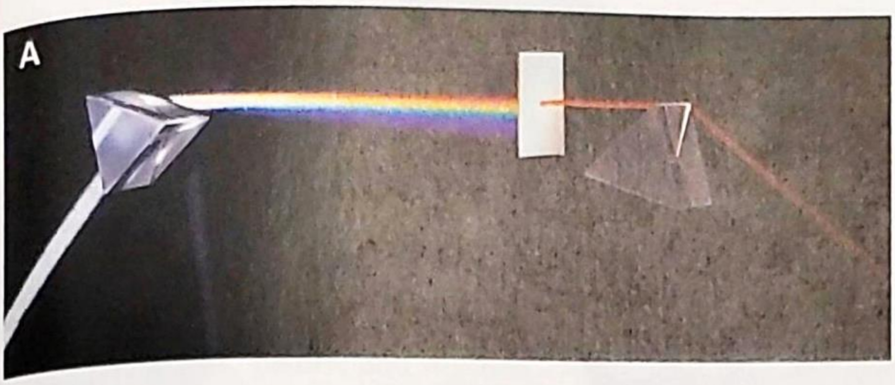
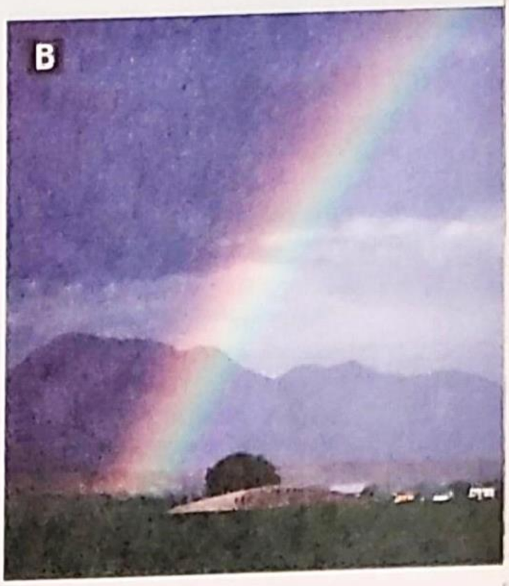


Figure 23 White light is dispersed by prisms and water droplets. **A** When white light passes through a prism, the shorter wavelengths are bent more than the longer wavelengths. The colors are separated. When red light enters the second prism, it is refracted but the color does not change. **B** Water droplets separate the colors of sunlight, producing a rainbow.



Separating White Light Into Colors

In 1666, the English physicist Isaac Newton investigated the visible spectrum. First, he used a glass prism to produce a visible spectrum from sunlight. With screens, he then blocked all colors of light except blue. Next, he placed a second prism where the blue light was visible. The second prism refracted the blue light but had no further effect on the color. Newton's experiments showed that white sunlight is made up of all the colors of the visible spectrum.

How does a prism separate white light into a visible spectrum? **As white light passes through a prism, shorter wavelengths refract more than longer wavelengths, and the colors separate.** Look at Figure 23A. When red light, with its longer wavelength, enters a glass prism, it slows down the least of all the colors, and so is bent the least. Violet light is bent the most. The process in which white light separates into colors is called **dispersion.**

A rainbow gives a beautiful example of dispersion. Droplets of water in the air act like prisms. They separate sunlight into the spectrum. When light enters a raindrop, it slows down and refracts. Then it reflects off the far inner surface of the raindrop. It refracts again as it exits the raindrop, speeds up, and travels back toward the source of the light.

Reading Checkpoint *What process causes a rainbow?*

The Colors of Objects

Would it surprise you to learn that an object of any color does not have a definite color? An object's color is the color of light that reaches your eye when you look at the object. **The color of any object depends on what the object is made of and on the color of light that strikes the object.** Sunlight contains all the colors of the visible spectrum. But when you look, for example, at a red car in sunlight, the red paint reflects mostly red light. Most of the other colors in white light are absorbed at the surface of the paint.

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Figure 24 Under white light, the pots appear white, green, yellow, red, and blue. **Observing** ***How does the red pot appear under red, green, and blue light?***

What happens if you change the color of the light shining on an object? Look at Figure 24, which shows the same stack of flower pots in several different colors of light. The pots appear to be different colors when viewed in different colors of light. For example, the red pot looks black when viewed in blue light because the red plastic absorbs all of the light striking it. No red light reaches the object, so none can be reflected from it.

Mixing Colors of Light

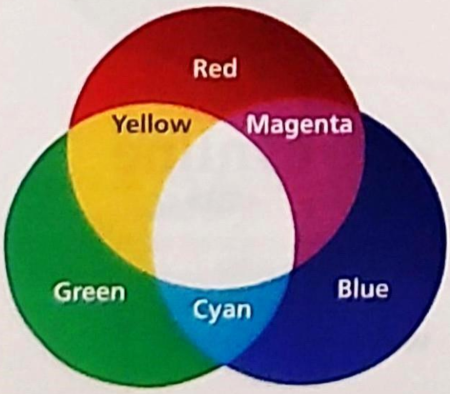
Figure 25 shows how equal amounts of three colors of light—red, green, and blue—combine to produce white light. **Primary colors** are three specific colors that can be combined in varying amounts to create all possible colors. **The primary colors of light are red, green, and blue.**

When red light strikes a white surface, red light is reflected. Similarly, when blue light strikes a white surface, blue light is reflected. What happens if both red light and blue light strike a white surface? Both colors are reflected and the two colors add together to make a third color, magenta. When colors of light are mixed together, the colors add together to form a new color.

The secondary colors of light are cyan, yellow, and magenta. Each **secondary color** of light is a combination of two primary colors. Therefore, if you add a primary color to the proper secondary color, you will get white light. Any two colors of light that combine to form white light are **complementary colors of light.** A complementary color pair is a combination of one primary color and one secondary color. Blue and yellow are complementary colors of light, as are red and cyan, and green and magenta.

Reading Checkpoint *How is a secondary color of light formed?*

Figure 25 The three primary colors of light are red, green, and blue. When any two primary colors combine, a secondary color is formed. **Observing** ***What color of light is produced when all three primary colors combine in equal amounts?***



Mixing Pigments

Paints, inks, photographs, and dyes get their colors from pigments. A **pigment** is a material that absorbs some colors of light and reflects other colors. Stone Age cave paintings were made with natural pigments from colored earth and clay. Over the centuries, natural pigments have been obtained from many sources, including metal oxide compounds, minerals, plants, and animals. Today's artists use paints made from natural pigments as well as from synthetic, or manufactured, pigments.

The primary colors of pigments are cyan, yellow, and magenta. Perhaps you have noticed that color printers and photocopiers use these three colors, plus black. You can mix varying amounts of these primary pigment colors to make almost any other color. Each pigment reflects one or more colors. As pigments are mixed together, more colors are absorbed and fewer colors are reflected. When two or more pigments are mixed together, the colors absorbed by each pigment are subtracted out of the light that strikes the mixture.

Look at Figure 26. The light filters absorb light in much the same way pigments do. When cyan and magenta are combined, blue is formed. Cyan and yellow combine to form green. Yellow and magenta combine to form red. The secondary colors of pigments are red, green, and blue. Any two colors of pigments that combine to make black pigment are **complementary colors of pigments.**

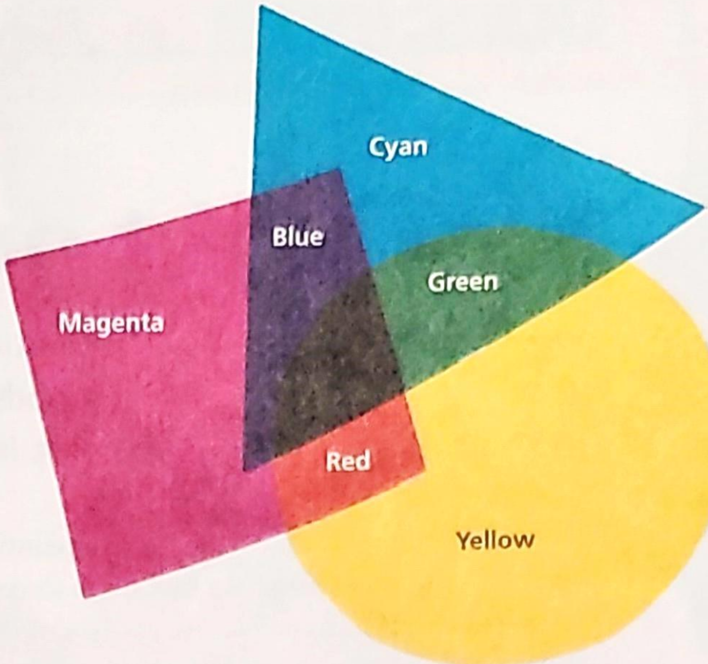


Figure 26 The three primary colors of pigments are cyan, yellow, and magenta. When the three primary colors of pigments are combined, the secondary colors of pigments are formed. **Interpreting Diagrams** ***Which colors of pigments combine to make black?***

Section 18.4 Assessment

Reviewing Concepts

1. Explain how a prism separates white light into the colors of the spectrum.
2. What determines the color of an object?
3. What three colors of light can combine to form any other color?
4. What three colors of pigments can combine to form any other color?
5. Explain how the process of dispersion of light forms a rainbow.
6. What are pigments? Explain how different pigments affect light.

Critical Thinking

7. **Predicting** What color would a blue wall appear under green light?
8. **Applying Concepts** Why does combining equal amounts of cyan, yellow, and magenta paints form black?

Writing in Science

Explain a Concept Write a letter to a friend who is not in class with you. Explain how an object gets its color. Give evidence and use examples to support your explanation.

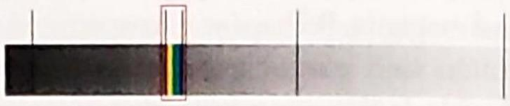
New Light on Old Art

How does an expert know if a painting is by a famous artist, or is a fake? Scientific methods use electromagnetic radiation—visible light, ultraviolet, infrared, and X-rays.

Scientific methods cannot prove that a painting is genuine, but they can prove that it is a forgery. Careful examination may reveal aspects of the painting—the artist's methods or the materials used—that come from a time period later than the supposed date of the painting.

The simplest techniques used to examine paintings are those involving visible light. Looking at a cross section of a paint sample with a microscope or hand lens shows how the artist built up the layers of paint.

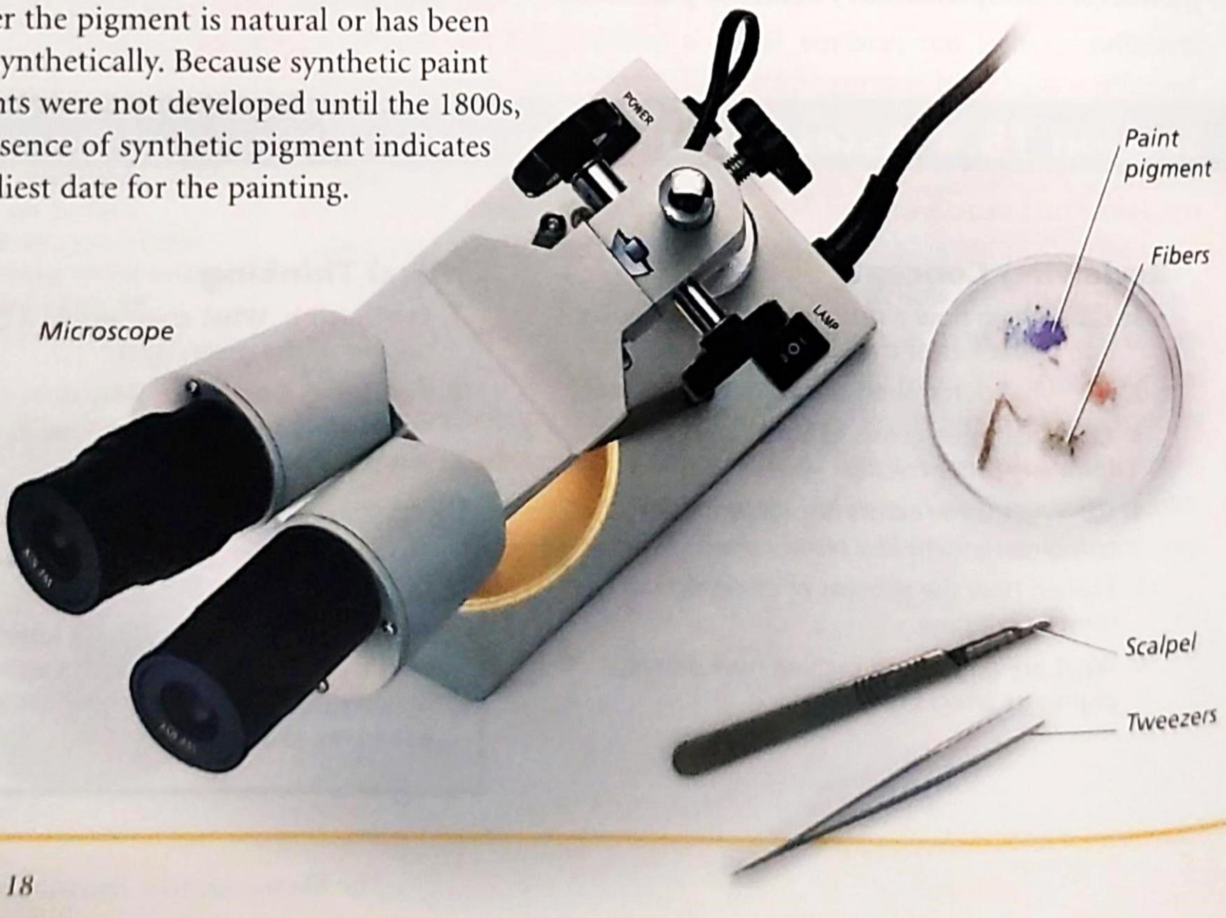
Scientists are able to examine the structure of the paint pigment in detail using high-powered microscopes. The structure can reveal whether the pigment is natural or has been made synthetically. Because synthetic paint pigments were not developed until the 1800s, the presence of synthetic pigment indicates the earliest date for the painting.



VISIBLE LIGHT

Interpreting visible light
This is the part of the electromagnetic spectrum to which human eyes are sensitive. Paint pigments reflect some parts of the visible spectrum and absorb others, so the eye perceives them as colored.

Examining samples
Using scalpels and tweezers, experts take tiny samples from a painting to examine the painted surface.



Examining the Paint Surface

Identifying the pigments used in a painting usually requires taking one or more tiny samples from the painting. This sampling must be done with extreme care.

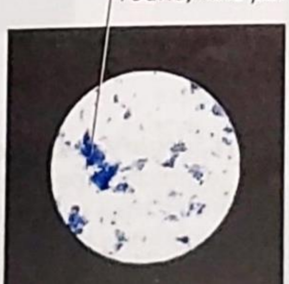
COCHINEAL BEETLES

BUCKTHORN BERRIES

Natural materials
Before the 1800s, most pigments used by artists were from natural sources. Many, including yellow lake, were obtained from plants. Some, such as carmine or cochineal, were of animal origin. Others, like ultramarine, came from minerals.

Lapis lazuli *was ground to a powder to make ultramarine pigment.*

Under the microscope
High magnifications (100 to 500 times) show the physical structure of pigment particles. Here, the particles in the sample of synthetic ultramarine are different from those in the natural sample. Synthetic ultramarine was introduced in 1828, so paintings using this pigment could not have been made earlier than that year.



Looking Beneath the Paint Surface

Rather than removing samples of the paint layer, non-invasive methods examine an intact painting by using the nonvisible regions of the electromagnetic spectrum. Ultraviolet, infrared, and X-rays can reveal many secrets that are invisible to the human eye.

Ultraviolet rays are best at showing surface features. The varnish that is the top layer of most paintings will fluoresce when exposed to ultraviolet. This fluorescence shows whether the original varnish has been disturbed.

Infrared rays can penetrate the layers of paint, so infrared imaging can be used to detect charcoal sketches and other images that are often hidden beneath the painted surface.

X-rays are used to look through a painting. X-rays are absorbed by dense materials and pass through others. Pigments that include metal atoms, such as white lead, show up clearly, as do metal objects used in the painting's construction. One forger was caught when X-rays revealed a machine-made nail in the wooden panel under a painting that was supposedly painted in the 1500s! Machine-made nails were not manufactured until the 1800s.

Interpreting ultraviolet radiation
Although transparent to visible light, the varnish layer on the surface of most paintings can be seen using ultraviolet rays. In this copy of Cranach's painting, the ultraviolet makes the varnish layer fluoresce. Dark regions show areas that have been retouched or painted over.

Darker areas have been retouched or painted over.

Art forgery detection
A technician operates an infrared scanner. He is examining a copy of a painting by the German painter Lucas Cranach the Elder (1472–1553).

INFRARED RAYS

Interpreting infrared imaging

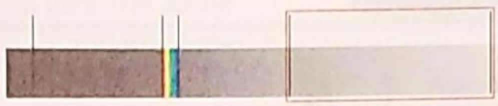
The penetrating power of infrared most often uncovers preliminary sketches. But infrared imaging can also reveal surprising changes in the development of a work of art. In this self-portrait by Judith Leyster about 1630, the infrared image reveals that the artist originally included a portrait of herself on the easel. But later she changed the portrait to a musician.

Merry musician in the final painting

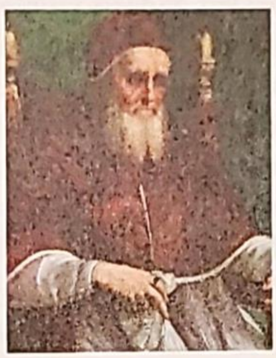
Infrared rays penetrate layers of paint, revealing an underlying self-portrait.

Part of the overpainted pattern of crossed keys

Horizontal wooden battens used to strengthen the panel



X-RAYS



Interpreting X-rays

X-rays can reveal the creative process at work. In this portrait of Pope Julius II, painted by Raphael in 1511–1512, the X-ray image shows a pattern of crossed keys on the wall behind the seated figure. The keys do not appear in visible light. Because oil paints are opaque to visible light, the artist probably simply painted over the keys.

Going Further

- Choose one of these painting styles to research: impressionism, surrealism, pointillism, or op art. Prepare an oral report to share with the class, including an explanation of the painting style, how light and color are used in the style, and three samples of the painting style.
- Take a Discovery Channel Video Field Trip by watching "Finding the Fakes."

Discovery Channel School Video Field Trip