28 COLOR

Objectives

- Describe what happens when sunlight is passed through a triangular-shaped prism. (28.1)
- Describe how the reflection of light affects an object's color. (28.2)
- Describe what determines whether a material reflects, transmits, or absorbs light of a particular color. (28.3)
- Describe white light. (28.4)
- State the three colors that can be combined to form almost any color. (28.5)
- Define complementary colors. (28.6)
- Describe color mixing by subtraction. (28.7)
- Explain why the sky is blue, why sunsets are red, and why water is greenish-blue. (28.8, 28.9, 28.10)
- Explain how atoms emit light. (28.11)

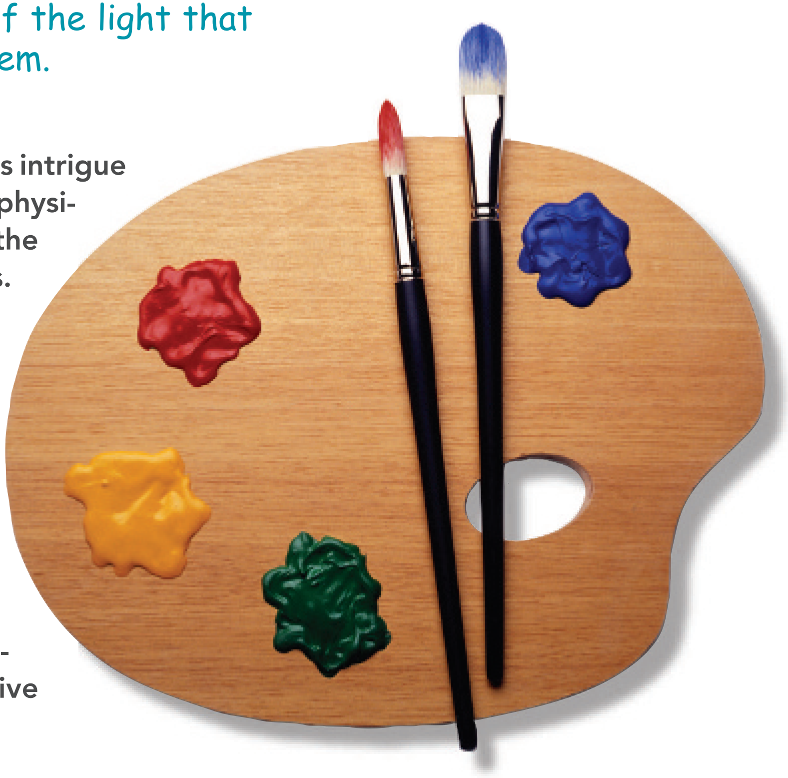
This interesting chapter can be taught very rigorously or it can be a plateau where physics is fun—I recommend the latter. Except for atomic spectra, it is not a prerequisite to chapters that follow.

PAUL

28 COLOR

THE BIG IDEA The colors of objects depend on the color of the light that illuminates them.

Roses are red and violets are blue; colors intrigue artists and physics types, too. To the physicist, the colors of things are not in the substances of the things themselves. Color is in the eye of the beholder and is provoked by the frequencies of light emitted or reflected by things. We see red in a rose when light of certain frequencies reaches our eyes. Other frequencies will provoke the sensations of other colors. Whether or not these frequencies of light are actually perceived as colors depends on the eye–brain system. Many organisms, including people with defective color vision, see no red in a rose.



discover!

How Can Color Be Used To Identify Elements?

1. View an incandescent bulb through a diffraction grating and record what you see using crayons or colored pencils.
2. View a fluorescent lamp through a diffraction grating. Record your observations.
3. View a light source of your choice using the diffraction grating and record your observations. **Caution:** Never view the sun through the diffraction grating. Looking directly at the sun can damage your eyes.

Analyze and Conclude

1. **Observing** In what ways were the colors you viewed the same? In what ways were the spectra different?
2. **Predicting** Do two incandescent bulbs of different brightness have the same colors?
3. **Making Generalizations** How may color be used to identify elements found both here on Earth and in space?

28.1 The Color Spectrum

Isaac Newton, shown in Figure 28.1, was the first to make a systematic study of color. **By passing a narrow beam of sunlight through a triangular-shaped glass prism, Newton showed that sunlight is composed of a mixture of all the colors of the rainbow.** The prism cast the sunlight into an elongated patch of colors on a sheet of white paper. Newton called this spread of colors a **spectrum** and noted that the colors were formed in the order red, orange, yellow, green, blue, and violet, as shown in Figure 28.2.

Sunlight is an example of what is called white light. **White light** is a combination of all the colors. Under white light, white objects appear white and colored objects appear in their individual colors. Newton showed that the colors in the spectrum were a property not of the prism but of white light itself. He demonstrated this when he recombined the colors with a second prism to produce white light again. In other words, all the colors, one atop the other, combine to produce white light. Strictly speaking, white is not a color but a combination of all colors.

FIGURE 28.1 ▲
Newton passed sunlight through a glass prism to form the color spectrum.

FIGURE 28.2 ▲
When sunlight passes through a prism, it separates into a spectrum of all the colors of the rainbow.

discover!

MATERIALS Crayons and different light sources

EXPECTED OUTCOME The colors in a light source are revealed when the light passes through a diffraction grating.

ANALYZE AND CONCLUDE

1. The spectrum from the incandescent bulb is a continuous spectrum. The spectra from the fluorescent lamps or gas discharge tubes are line spectra.
2. Yes; bulbs of different brightness still have the same composition, so the spectra should be the same for each bulb.
3. Since each element emits a unique collection of colors, you can use spectra to identify elements.

28.1 The Color Spectrum

Key Terms
spectrum, white light

Common Misconception
White and black are colors.

FACT White is a combination of all colors of light, and black is the absence of light.

▶ **Teaching Tip** Compare the physics of the black-edged stack of razor blades in Figure 28.3 with the black pupils of our eyes. Explain that both are a result of the absorption of light.

CONCEPT CHECK By passing a narrow beam of sunlight through a triangular-shaped glass prism, Newton showed that sunlight is composed of a mixture of all the colors of the rainbow.

Teaching Resources

- **Reading and Study Workbook**
- **Presentation*EXPRESS***
- **Interactive Textbook**
- **Conceptual Physics Alive! DVDs** *Light and Color*

28.2 Color by Reflection

▶ **Teaching Tip** Explain that the model chosen to explain color is the *oscillator*—electrons of an atom are forced to vibrate by the oscillations of light waves. (There is a small difference between *oscillate* and *vibrate:* Vibrate usually refers to motion of matter (mechanical); oscillate usually refers to motion of electrons and the electromagnetic field. The source of a wave vibrates, and the wave oscillates.)

▶ **Teaching Tip** Display different colored objects while you discuss the oscillator model of the atom, and the ideas of forced vibration and resonance as they relate to color.

FIGURE 28.3 ▲
When a stack of razor blades bolted together is viewed end on, the edges appear black. Light that enters the wedge-shaped spaces between the blades is reflected so many times that most of it is absorbed.

Black is similarly not a color itself, but is the absence of light. Objects appear black when they absorb light of all visible frequencies. Carbon soot is an excellent absorber of light and looks very black. The dull finish of black velvet is an excellent absorber also. But even a polished surface may look black under some conditions. For example, highly polished razor blades are not black, but when stacked together and viewed end on as in Figure 28.3, they appear quite black. Most of the light that gets between the closely spaced edges of the blades gets trapped and is absorbed after being reflected many times.

Black objects that you can see do not absorb all light that falls on them, for there is always some reflection at the surface. If not, you wouldn't be able to see them.

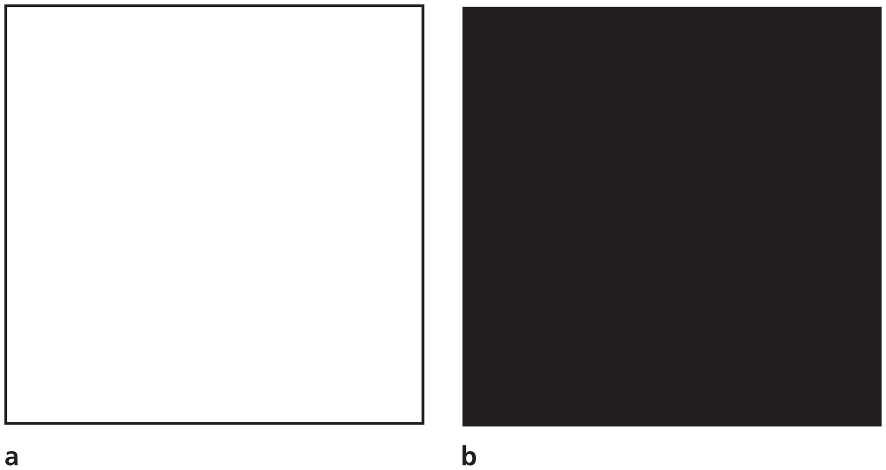
CONCEPT CHECK **How did Isaac Newton show that sunlight is composed of a mixture of all colors of the rainbow?**

28.2 Color by Reflection

The colors of most objects around you are due to the way the objects reflect light. ✓ **The color of an opaque object is the color of the light it reflects.** Light is reflected from objects in a manner similar to the way sound is "reflected" from a tuning fork when another that is nearby sets it into vibration. A tuning fork can be made to vibrate even when the frequencies are not matched, although at significantly reduced amplitudes. The same is true of atoms and molecules. We can think of atoms and molecules as three-dimensional tuning forks with electrons that behave as tiny oscillators that whirl in orbits around the nuclei. Electrons can be forced temporarily into larger orbits by the vibrations of electromagnetic waves (such as light). Like acoustical tuning forks, once excited to more vigorous motion, electrons send out their own energy waves in all directions.

Link to ZOOLOGY

Chameleons
The chameleon can change its color to blend into its background or to suit its mood. Its skin consists of stacks of cells with red, yellow, and blue pigments, as well as brown melanin. The chameleon expands cells of one color while shrinking those of the others to create different skin hues. A chameleon's color depends on whether it is lounging, flirting, or fighting. When the chameleon is angry, melanin levels go up, masking the other colors, and the skin looks dark.



◀ **FIGURE 28.4**
a. This square *reflects* all the colors illuminating it. In sunlight it is white. When illuminated with blue light, it is blue.
b. This square *absorbs* all the colors illuminating it. In sunlight it is warmer than the white square.

Differences Among Materials Different materials have different natural frequencies for absorbing and emitting radiation. In one material, electrons oscillate readily at certain frequencies; in another material, they oscillate readily at different frequencies. At the resonant frequencies where the amplitudes of oscillation are large, light is absorbed (recall from the previous chapter that glass absorbs ultraviolet light for this reason). But at frequencies below and above the resonant frequencies, light is reemitted. If the material is transparent, the reemitted light passes through it. If the material is opaque, the light passes back into the medium from which it came. This is reflection.

Most materials absorb light of some frequencies and reflect the rest. If a material absorbs light of most visible frequencies and reflects red, for example, the material appears red. If it reflects light of all the visible frequencies, as shown in Figure 28.4a, it will be the same color as the light that shines on it. If a material absorbs all the light that shines on it, as shown in Figure 28.4b, it reflects none and is black.

When white light falls on a flower, light of some frequencies is absorbed by the cells in the flower and some light is reflected. Cells that contain chlorophyll absorb light of most frequencies incident upon them and reflect the green part, so they appear green. The petals of a red rose, on the other hand, reflect primarily red light, with a lesser amount of blue. Interestingly enough, the petals of most yellow flowers, such as daffodils, reflect red and green as well as yellow. Yellow daffodils reflect light of a broad band of frequencies. The reflected colors of most objects are not pure single-frequency colors, but are composed of a spread of frequencies. So something yellow, for example, may simply be a mixture of colors without blue and violet—or it can be built of red and green together.

think!

When red light shines on a red rose, why do the leaves become warmer than the petals?
Answer: 28.2.1

When green light shines on a red rose, why do the petals look black?
Answer: 28.2.2

▶ **Teaching Tip** Discuss the color spectrum, and the nonspectral "colors" white and black. Refer back to the box with a white interior that has a hole in it, as shown in Figure 22.14 on page 439.

▶ **Teaching Tip** Point out that the colors of nonluminous objects are the colors of the light they reflect or the light they transmit.

CONCEPT CHECK The color of an opaque object is the color of the light it reflects.

Teaching Resources

- **Reading and Study Workbook**
- **Presentation*EXPRESS***
- **Interactive Textbook**

28.3 Color by Transmission

Key Term
pigment

Be sure your students have seen and heard a demonstration of resonance with tuning forks. Resonance is a central idea in this chapter; the tuning fork model accounts for selective light reflection and transmission.

PAUL

CONCEPT CHECK The color of a transparent object is the color of the light it transmits.

28.4 Sunlight

▶ **Teaching Tip** The text emphasizes frequency rather than wavelength to explain color. Either is acceptable. A point to note is that wavelength changes when light changes speed, but its frequency does not. When light enters a new medium, its color does not change because its frequency does not change.

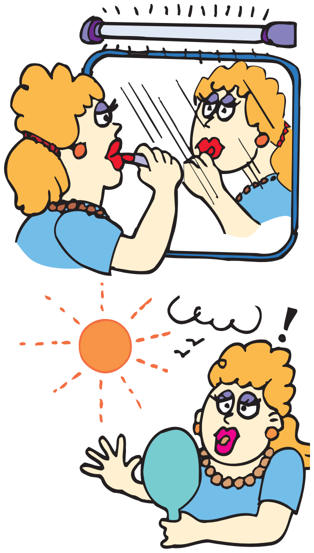


FIGURE 28.5 ▲
Color depends on the light source.

Light Sources An object can reflect only light of frequencies present in the illuminating light. The color of an object therefore depends on the kind of light used. A candle flame emits light that is deficient in the higher frequencies; it emits a yellowish light. Things look yellowish in candlelight. An incandescent lamp emits light of all the visible frequencies, but is richer toward the lower frequencies, enhancing the reds. A fluorescent lamp is richer in the higher frequencies, so blues are enhanced when illuminated with fluorescent lamps. In a fabric with a little bit of red, for example, the red will be more apparent when illuminated with an incandescent lamp than with a fluorescent lamp. Colors in daylight appear different from the way they appear when illuminated with either of these lamps, as shown in Figure 28.5. The perceived color of an object is subjective, although color differences between two objects are most easily detected in bright sunlight.

CONCEPT CHECK **What determines the color of an opaque object?**

28.3 Color by Transmission

✓ **The color of a transparent object is the color of the light it transmits.** A red piece of glass appears red because it absorbs all the colors that compose white light, except red, which it transmits. The blue piece of glass in Figure 28.6 appears blue because it transmits primarily blue and absorbs the other colors that illuminate it.

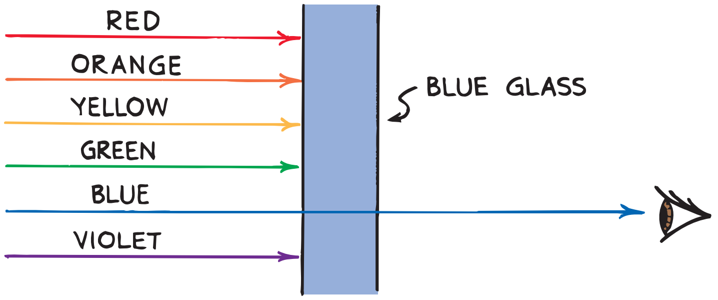


FIGURE 28.6 ▶
Blue glass transmits only energy of the frequency of blue light; energy of the other frequencies is absorbed and warms the glass.

The material in the glass that selectively absorbs colored light is known as a **pigment.** From an atomic point of view, electrons in the pigment atoms selectively absorb light of certain frequencies in the illuminating light. Light of other frequencies is reemitted from atom to atom in the glass. The energy of the absorbed light increases the kinetic energy of the atoms, and the glass is warmed. Ordinary window glass is colorless because it transmits light of all visible frequencies equally well.

CONCEPT CHECK **What determines the color of a transparent object?**

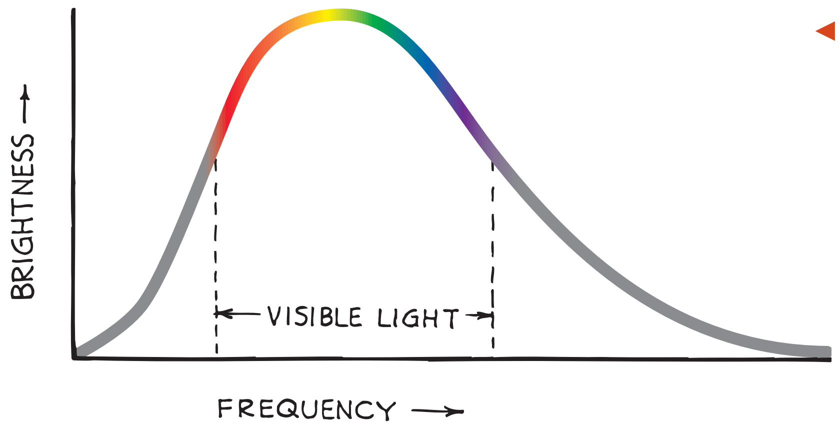


FIGURE 28.7
The radiation curve of sunlight is a graph of brightness versus frequency. Sunlight is brightest in the yellow-green region, in the middle of the visible range.

28.4 Sunlight

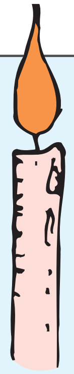
White light from the sun is a composite of all the visible frequencies. The brightness of solar frequencies is uneven, as indicated in the graph of brightness versus frequency in Figure 28.7. The graph indicates that the lowest frequencies of sunlight, in the red region, are not as bright as those in the middle-range yellow and green region. **Yellow-green light is the brightest part of sunlight.** Since humans evolved in the presence of sunlight, it is not surprising that we are most sensitive to yellow-green. That is why it is more and more common for new fire engines to be painted yellow-green, particularly at airports where visibility is vital. This also explains why at night we are able to see better under the illumination of yellow sodium-vapor lamps than we are under tungsten lamps of the same brightness. The blue portion of sunlight is not as bright, and the violet portion is even less bright.

The graphical distribution of brightness versus frequency in Figure 28.7 is called the *radiation curve* of sunlight. Most whites produced from reflected sunlight have this frequency distribution.

CONCEPT CHECK Which visible frequencies make up the brightest part of sunlight?

discover!

What is the Color of a Candle's Reflection?



1. Hold a candle flame, match flame, or any small source of white light in between you and a piece of colored glass. How many reflections do you see?
2. What is the color of the flame reflected from the front surface? From the back surface?
3. **Think** Explain why the flame's reflections are the color(s) that they are.

Teaching Tip Explain that the source of all light is accelerating electrons. The internal energy of the sun shakes its electrons so violently that waves of energy bathe the solar system and extend beyond. These waves of energy make up sunlight, which is made up of a wide range of frequencies.

Teaching Tip Draw the radiation curve for sunlight on the board (Figure 28.7). Go further than the text, and divide the visible portion into thirds—a low-frequency section that averages to red, a middle section that averages to green, and a high-frequency section that averages to blue. These three regions correspond to the three regions of color to which our retinas are sensitive. Red, green, and blue are the three primary colors of white light.

CONCEPT CHECK Yellow-green light is the brightest part of sunlight.

discover!

MATERIALS candle or match, piece of colored glass

EXPECTED OUTCOME The reflection from the front surface is the same color as the flame and the reflection from the back surface is the same color as the glass.

THINK The only color of light the glass transmits is that which is the same color as the glass. Therefore, this is the only color of light that can be reflected from the back.

28.5 Mixing Colored Light

Key Term
additive primary colors

Demonstration

Mount three floodlights, red, green, and blue, on your lecture table, so that all three overlapping produce white on a white screen. Party lights or 75-W colored bulbs work well. Dim the room lights and stand in front of the lamps, turning them on one at a time to show the interesting colors of the shadows. Or, use slide projectors and red, green, and blue filters to show how white light can be produced.

Physics on the Job

Artist

Artists use both creativity and science to paint. By mixing pigments in just the right proportions, an artist can produce all of the colors necessary to capture an image. To artists, mixing colors can be a matter of trial and error. They add colors until they achieve the desired color. As they do so, they are using the process of color mixing by subtraction. Some artists work independently, selling their works to interested buyers. Others are employed to create images for books, movies, or advertisements.

28.5 Mixing Colored Light

think!

What color does red light plus blue light make?
Answer: 28.5

Light of all the visible frequencies mixed together produces white. Interestingly enough, white also results from the combination of only red, green, and blue light. When a combination of only red, green, and blue light of equal brightness is overlapped on a screen, as shown in Figure 28.8, it appears white. Where red and green light alone overlap, the screen appears yellow. Red and blue light alone produce the bluish red color called *magenta.* Green and blue light alone produce the greenish blue color called *cyan.*

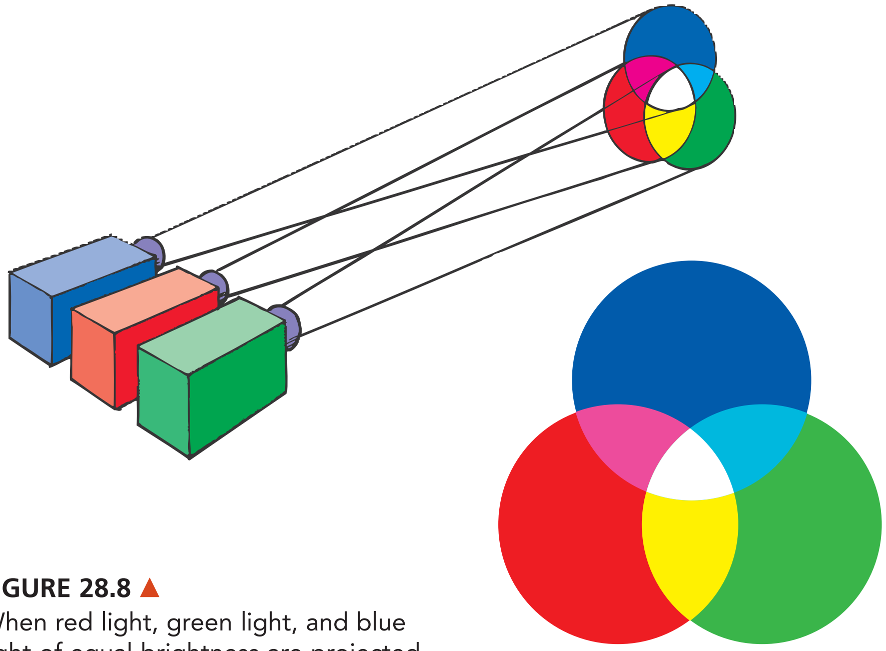


FIGURE 28.8 ▲
When red light, green light, and blue light of equal brightness are projected on a white screen, the overlapping areas appear different colors. Where all three overlap, white is produced.

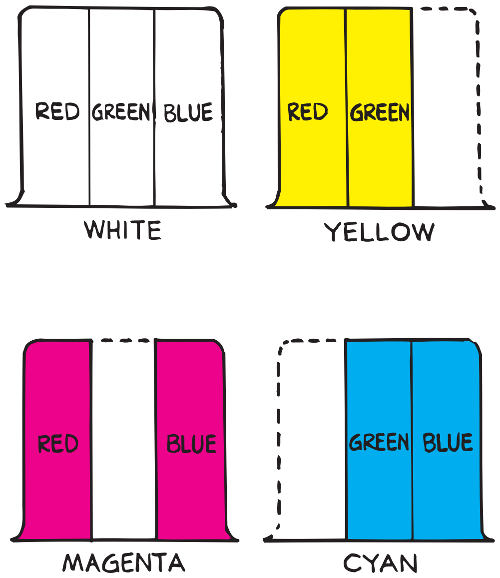


FIGURE 28.9
The low-frequency, middle-frequency, and high-frequency parts of white light appear *red, green,* and *blue.* To the human eye, red + green = yellow; red + blue = magenta; green + blue = cyan.

This can be understood if the frequencies of white light are divided into three regions as shown in Figure 28.9: the lower-frequency red end, the middle-frequency green part, and the higher-frequency blue end. The low and middle frequencies combined appear yellow to the human eye. The middle and high frequencies combined appear greenish blue (cyan). The low and high frequencies combined appear bluish red (magenta).

✓ **You can make almost any color at all by overlapping red, green, and blue light and adjusting the brightness of each color of light.** This amazing phenomenon is due to the way the human eye works. The three colors do not have to be red, green, and blue, although those three produce the highest number of different colors. For this reason red, green, and blue are called the **additive primary colors.**

Color television is based on the ability of the human eye to see combinations of three colors as a variety of different colors. A close examination of the picture on most color television tubes will reveal that the picture is made up of an assemblage of tiny spots, each less than a millimeter across. When the screen is lit, some of the spots are red, some green, and some blue. At a distance the mixtures of these colors provide a complete range of colors, plus white.[28.5]

CONCEPT CHECK Which three visible frequencies combine to form almost any color?

Go Online
NSTA SCiLINKS™
For: Links on color
Visit: www.SciLinks.org
Web Code: csn – 2805

CONCEPT CHECK You can make almost any color at all by overlapping red, green, and blue light and adjusting the brightness of each color of light.

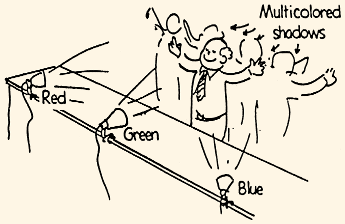
Teaching Resources
- **Reading and Study Workbook**
- **Transparency *60***
- **Presentation*EXPRESS***
- **Interactive Textbook**
- **Next-Time Question *28-1***

28.6 Complementary Colors

Key Term
complementary colors

Demonstration

Place three lamps, red, green, and blue, at least 1 m apart from one another. With the room dark, stand between a white surface and the three lamps. Turn the lamps on one at a time and discuss what is seen at each stage. First, turn on the red lamp and view your black shadow. Then turn on the green lamp and show that the black shadow cast by the red light is now illuminated by green light (as if the red light were casting a green shadow). Note that the shadow cast by the green light is not black, but the same red as the red that was there before the green light was switched on! Note the yellow wherever red and green overlap. Finally, turn on the blue light and the yellow background becomes white. Now you have a third shadow. Ask your students to account for the colors of your shadow.



think!

What color does white light minus yellow light appear? *Answer: 28.6.1*

What color does white light minus green light appear? *Answer: 28.6.2*

28.6 Complementary Colors

What happens when two of the three additive primary colors are combined?

red + green = yellow

red + blue = magenta

blue + green = cyan

Now, a little thought and inspection of Figure 28.8 will show that when we add in the third color, we get white.

yellow + blue = white

magenta + green = white

cyan + red = white

When two colors are added together to produce white, they are called **complementary colors.** For example, we see that yellow and blue are complementary because yellow, after all, is the combination of red and green. And red, green, and blue light together appear white. By similar reasoning we see that magenta and green are complementary colors, as are cyan and red. ✓ **Every color has some complementary color that when added to it will produce white.** Figure 28.10 shows how six blocks and their shadows appear different colors under light of different colors.

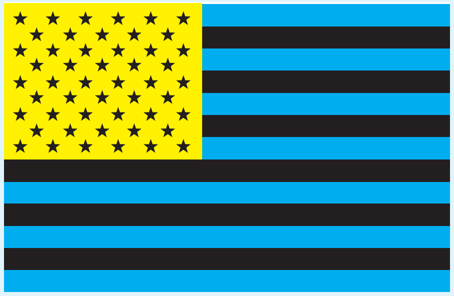
FIGURE 28.10 ▼
Six blocks and their shadows appear as different colors depending on the color of light that illuminates them.


a. The blocks are lit by white light.
b. The blocks are lit by blue light.


c. The blocks are lit by red light from the right and green light from the left.
d. The blocks are lit by blue light from the left and red light from the right.

discover!

What Do You See When Your Color Receptors Are Fatigued?



1. What are the complementary colors of the flag?
2. Stare at the flag for a minute or so.
3. Then look at a white piece of paper.
4. What are the colors of the afterimage?
5. **Think** When you stare at a colored object for a while, the color receptors in your eyeballs become fatigued. The fatigued receptors send a weaker signal to the brain. Use this idea to explain the colors of the afterimage.

Now, if you begin with white light and *subtract* some color from it, the resulting color will appear as the complement of the one subtracted. Not all the light incident upon an object is reflected. Some is absorbed. The part that is absorbed is in effect subtracted from the incident light, as shown in Figure 28.11. For example, if white light falls on a pigment that absorbs red light, the light reflected appears cyan. A pigment that absorbs blue light will appear yellow; similarly, a pigment that absorbs yellow light will appear blue. Whenever you subtract a color from white light, you end up with the complementary color.

CONCEPT CHECK **What happens when you combine any color with its complementary color?**

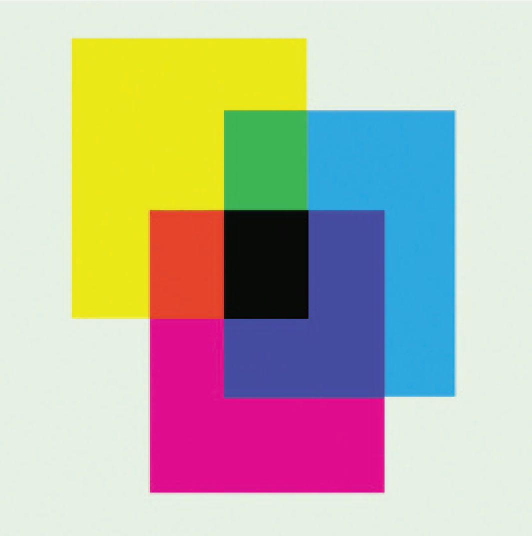


FIGURE 28.11
When white light passes through all three transparencies, light of all frequencies is blocked (subtracted) and we have black. Where only yellow and cyan overlap, light of all frequencies except green is subtracted.

discover!

THINK When the eye looks at a strong color for a long time, the cones for that color become fatigued. If the eye then looks at a white surface, there is a strong afterimage of the complementary color. Since the complementary colors of cyan, black, and yellow are red, white, and blue respectively, the afterimage of the cyan, black, and yellow flag will be red, white, and blue.

▶ **Teaching Tip** Explain that the shadows in Figure 28.10 show the colors of the illuminating lamps. For example, the top right photo indicates that a blue lamp is at the right because it casts a shadow to the left. The bottom right photo indicates that a blue lamp is at the left casting a shadow to the right, which is subsequently lit by a red lamp there. The red lamp casts its shadow to the left end of the blocks, which is lit by the blue lamp there. The blue and red produce the magenta background. Point out that a single lamp would cast a black shadow. A second lamp fills in the shadow with its color. The color of the shadow is the color of the lamp that doesn't cast the shadow.

CONCEPT CHECK Every color has some complementary color that when added to it will produce white.

Teaching Resources

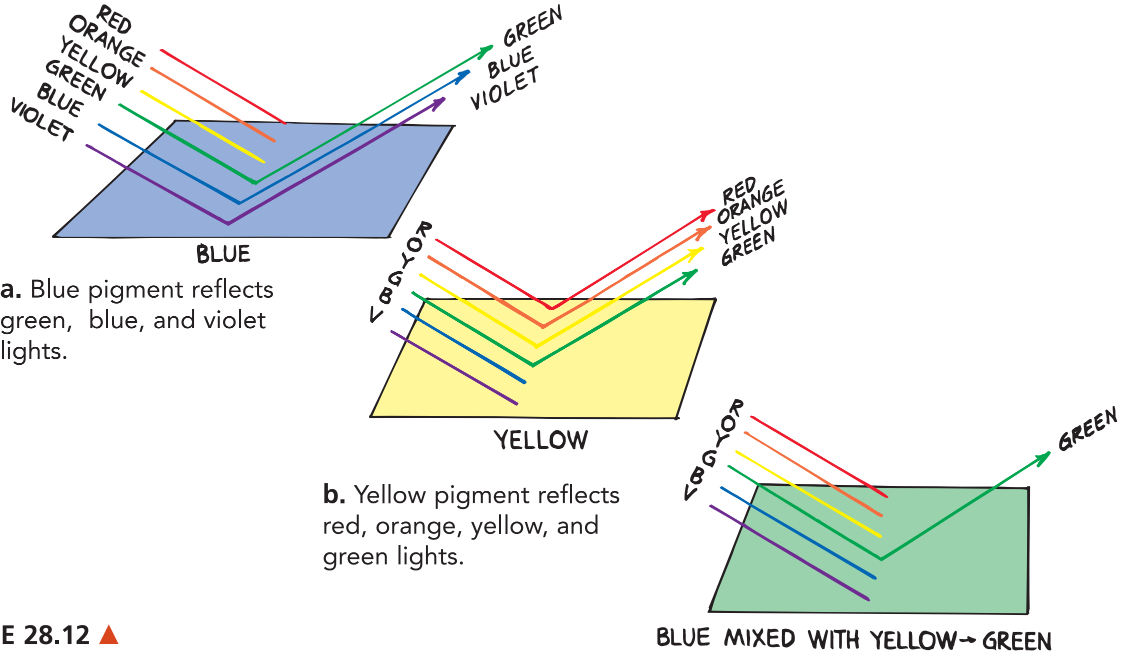
- **Reading and Study Workbook**
- **Concept-Development Practice Book** *28-1*
- **Transparency** *61*
- **Presentation*EXPRESS***

28.7 Mixing Colored Pigments

Key Term
subtractive primary colors

Teaching Tip Address color mixing as it relates to students' early fingerpainting experience (blue + yellow = green; red + yellow = orange; red + blue = purple). This was probably the only color mixing information previously given to your students. Distinguish between the colors that we see as a result of absorption (color mixing by subtraction), and the effect of superposing colored lights (color mixing by addition).

Teaching Tip An interesting point to note is that there are no blue pigments in the feather of a blue jay. Instead there are tiny alveolar cells in the barbs of its feathers that scatter light—mainly high-frequency light. So a blue jay is blue for the same reason the sky is blue—scattering. Interestingly enough, although brown eyes in people are due to pigments, the blue in blue eyes is similarly due to scattering from tiny spheres in the iris.



a. Blue pigment reflects green, blue, and violet lights.

b. Yellow pigment reflects red, orange, yellow, and green lights.

BLUE MIXED WITH YELLOW→GREEN

c. When blue and yellow pigments are mixed, the only common color reflected is green.

FIGURE 28.12 ▲
When blue and yellow pigments are mixed, they produce a green mixture.

FIGURE 28.13 ▲
Sneezlee's rich colors represent many frequencies of light. The photo, however, is a mixture of only yellow, magenta, cyan, and black.

28.7 Mixing Colored Pigments

Artists know that if we mix red, green, and blue paint, the result will be not white but a muddy dark brown. Red and green paint certainly do not combine to form yellow as red and green light do. The mixing of paints and dyes is an entirely different process from the mixing of colored light.

Paints and dyes contain finely divided solid particles of pigment that produce their colors by absorbing light of certain frequencies and reflecting light of other frequencies. Pigments absorb light of a relatively wide range of frequencies and reflect a wide range as well. In this sense, pigments reflect a mixture of colors.

When paints or dyes are mixed, the mixture absorbs all the frequencies each paint or dye in it absorbs. Blue paint, for example, reflects mostly blue light, but also violet and green; it absorbs red, orange, and yellow light. Yellow paint reflects mostly yellow light, but also red, orange, and green; it absorbs blue and violet light. When blue and yellow paints are mixed, then between them they absorb all the colors except green.

As Figure 28.12 shows, the only color both yellow and blue pigments reflect is green, which is why the mixture looks green. This process is called *color mixing by subtraction,* to distinguish it from the effect of mixing colored light, which is called *color mixing by addition.*

So when you cast lights on the stage at a school play, you use the rules of color addition to produce various colors. But when you mix paint, you use the rules of color subtraction.

You may have learned as a child that you can make any color with paints of three so-called primary colors: red, yellow, and blue. Actually, the three paint or dye colors that are most useful in color mixing by subtraction are magenta (bluish red), yellow, and cyan (greenish blue). Magenta, yellow, and cyan are the **subtractive primary colors,** used in printing illustrations in full color.[28.7]

Table 28.1 Color Subtractions

Pigment	Absorbs	Reflects
red	blue, green	red
green	blue, red	green
blue	red, green	blue
yellow	blue	red, green
cyan	red	green, blue
magenta	green	red, blue

Color printing is done on a press that prints each page with four differently colored inks (magenta, yellow, cyan, and black) in succession. Each color of ink comes from a different plate, which transfers the ink to the paper. The ink deposits are regulated on different parts of the plate by tiny dots. Examine the colored pictures in this book, or in any magazine, with a magnifying glass and see how the overlapping dots of three colors plus black give the appearance of many colors. Figure 28.14 shows how to reproduce a photograph.

CONCEPT CHECK Which visible frequencies are absorbed by a mixture of paints or dyes?


a. magenta **b.** yellow **c.** cyan


d. magenta + yellow + cyan **e.** black **f.** magenta + yellow + cyan + black

FIGURE 28.14 ▲
Only four colors of ink are used to print color illustrations and photographs—magenta, yellow, cyan, and black. The addition of black produces the finished result.

▶ **Teaching Tip** Pass a magnifying glass around and allow students to look at the cyan, magenta, and yellow dots that make up the colors in Figure 28.14 and in magazines and colored newspapers.

Did you know that the human eye can distinguish nearly 8 million differences in color?

PAUL

CONCEPT CHECK When paints or dyes are mixed, the mixture absorbs all the frequencies each paint or dye absorbs.

Teaching Resources

- **Reading and Study Workbook**
- **Transparencies *62–66***
- **Presentation*EXPRESS***
- **Interactive Textbook**

28.8 Why the Sky Is Blue

Key Term
scattering

▶ **Teaching Tip** Point out that the sky looks blue only when viewed against the blackness of space (or the darkness of distant mountains, in which case the mountains appear blue). The blue is really not very bright, as is reported by astronauts who see no blue when looking straight downward from orbit. Then, the brightness of reflected light from Earth overwhelms the weak blue.

▶ **Teaching Tip** Discuss the blueness of distant dark mountains and the yellowness of distant snow-covered mountains.

▶ **Teaching Tip** Compare the molecules in the atmosphere to tiny bells; when "struck," they "ring" with high frequencies. They "ring" most at violet, and next at blue. We're better at "hearing" blue, so we "hear" a blue sky. On the other hand, bumblebees and other creatures with good vision in violet see a violet sky. So if we were better at seeing violet, our sky would be violet.

▶ **Teaching Tip** Explain that larger molecules and particles, like larger bells, ring at lower frequencies. Very large ones ring in the reds. In a cloud there is a wide assortment of particles—all sizes. They ring with all colors. Ask your students if they have any idea why clouds are white! (Cumulus clouds are composed of droplets and are white because of the multitude of particle sizes, but higher-altitude cirrus clouds are composed of ice crystals, which, like snow, reflect all frequencies.)

28.8 Why the Sky Is Blue

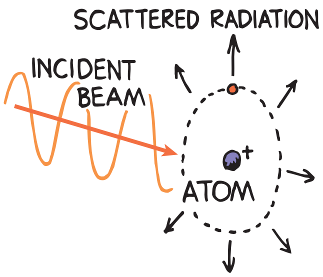


FIGURE 28.15 ▲
A beam of light falls on an atom and causes the electrons in the atom to move temporarily in larger orbits. The more vigorously oscillating electrons reemit light in various directions. Light is scattered.

If a sound beam of a particular frequency is directed to a tuning fork of similar frequency, the tuning fork will be set into vibration and effectively redirect the beam in multiple directions. The tuning fork scatters the sound. **Scattering** is a process in which sound or light is absorbed and reemitted in all directions. Figure 28.15 illustrates how an atom can scatter a beam of light. In the atmosphere, light is scattered by molecules and larger specks of matter that are far apart from one another.

The Sky We know that atoms and molecules behave like tiny optical tuning forks and reemit light waves that shine on them. Very tiny particles do the same. The tinier the particle, the higher the frequency of light it will scatter. This is similar to small bells ringing with higher notes than larger bells. The nitrogen and oxygen molecules and the tiny particles that make up the atmosphere are like tiny bells that "ring" with high frequencies when energized by sunlight. Like the sound from bells, the reemitted light is sent in all directions. It is scattered.

FIGURE 28.16 ▶
The sky is blue because its tiny particles scatter high-frequency light. The blue "sky" between the viewer and the distant mountains produces bluish mountains.

Most of the ultraviolet light from the sun is absorbed by a protective layer of ozone gas in the upper atmosphere. The remaining ultraviolet sunlight passing through the atmosphere is scattered by atmospheric particles and molecules. **The sky is blue because its component particles scatter high-frequency light.** Of the visible frequencies, violet light is scattered the most, followed by blue, green, yellow, orange, and red, in that order. Red light is scattered only a tenth as much as violet. Although violet light is scattered more than blue, our eyes are not very sensitive to violet light. Our eyes are more sensitive to blue, so we see a blue sky, as shown in Figure 28.16.

FIGURE 28.17
The droplets that compose a cloud come in a wide variety of sizes. Hence a wide variety of colors are scattered, which is why the cloud is white.

The blue of the sky varies in different places under different conditions. Where there are a lot of particles of dust and other particles larger than oxygen and nitrogen molecules, the lower frequencies of light are scattered more. This makes the sky less blue, and it takes on a whitish appearance. After a heavy rainstorm, when the particles have been washed away, the sky becomes a deeper blue.

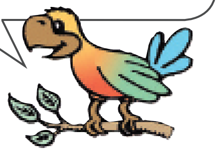
The higher that one goes into the atmosphere, the fewer molecules there are in the air to scatter light. The sky appears darker. When there are no molecules, as on the moon for example, the "sky" is black.

The Clouds Water droplets in a variety of sizes—some of them microscopic—make up clouds. The different-size droplets result in a variety of frequencies for scattered light: low frequencies from larger droplets and high frequencies from tinier droplets of water molecules. The overall result is a white cloud, as shown in Figure 28.17. The electrons in a tiny droplet vibrate together and in step, which results in the scattering of a greater amount of energy than when the same number of electrons vibrate separately. Hence, clouds are bright!

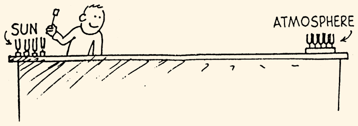
Larger assortment of droplets absorb much of the light incident upon them, and so the intensity of the scattered light is less. This contributes to the darkness of clouds composed of larger droplets. Further increase in the size of the droplets causes them to fall as raindrops, and we have rain.

CONCEPT CHECK **Why is the sky blue?**

There are no blue pigments in the feathers of a blue jay. Instead there are tiny alveolar cells in the barbs of its feather that scatter light—mainly high-frequency light. So a blue jay is blue for the same reason the sky is blue—scattering.



Demonstration



Place six tuning forks of different frequencies at one end of your lecture table—call them "red," "orange," "yellow," "green," "blue," and "violet." Ask your class what "color" sound they would hear if you struck all the tuning forks in unison (white). Then suppose you have a mirror device around the forks so that when you "light" (strike) them again, a beam of sound travels down the length of your lecture table. Ask what "color" they will hear. Now place a tray of tuning forks at the opposite end of your lecture table. The length of your lecture table represents the 150 million km between Earth and the sun. Your tray of assorted tuning forks represents Earth's atmosphere. Call out the "colors" of the forks, emphasizing the preponderance of blue and violet forks. Walk to the sun end of the table and show how the beam travels down the table and intercepts and scatters from the atmospheric tuning forks in all directions. Ask what "color" the class hears.

CONCEPT CHECK The sky is blue because its component particles scatter high-frequency light.

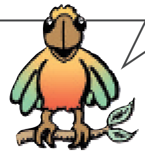
Teaching Resources

- **Laboratory Manual** *76*

28.9 Why Sunsets Are Red

Teaching Tip Using Figure 28.18, explain that at sunset the sunlight must go through many kilometers of air to reach an observer and that blue light is scattered all along this distance. Go back to the sun and Earth forks demonstration. Select a student to sit behind the tray of Earth forks. State that your volunteer represents an Earth observer at sunset. Go back and pretend to strike the sun forks. Follow the "beam" down the table. As it enters Earth's atmosphere, most of it scatters throughout the classroom. Again, ask the class what "color" they "hear."(Blue) Ask your volunteer what color he or she heard. (White) The thin noontime atmosphere did little to the white beam from the sun. Rotate the tray of forks that represent Earth's atmosphere 90° to simulate a thicker atmosphere. Go back to your sun and repeat the process. When your light reaches the Earth tuning forks, ask your class what color they hear. (Although blue is still the correct answer, many will say orange.) Emphasize that blue is still the color they see because of the preponderance of blue forks, seen from any angle except straight on. Now ask your volunteer what color he or she hears. (Orange) By "experiment" you have proved your point. Your volunteer has simply heard a composite of the lower-frequency left-over colors after the class received almost all the higher-frequency blues. So the pretty colors at sunset are actually left-over colors!

Atmospheric soot warms Earth's atmosphere by absorbing light, while cooling local regions by blocking sunlight from reaching the ground. The effects of soot particles in the air range from triggering severe rains in one region to causing droughts and dust storms in another.



28.9 Why Sunsets Are Red

The lower frequencies of light are scattered the least by nitrogen and oxygen molecules. Therefore red, orange, and yellow light are transmitted through the atmosphere more readily than violet and blue. Red light, which is scattered the least, passes through more atmosphere without interacting with matter than light of any other color. Therefore, when light passes through a thick atmosphere, light of the lower frequencies is transmitted while light of the higher frequencies is scattered. At dawn and at sunset, sunlight reaches us through a longer path through the atmosphere than at noon.

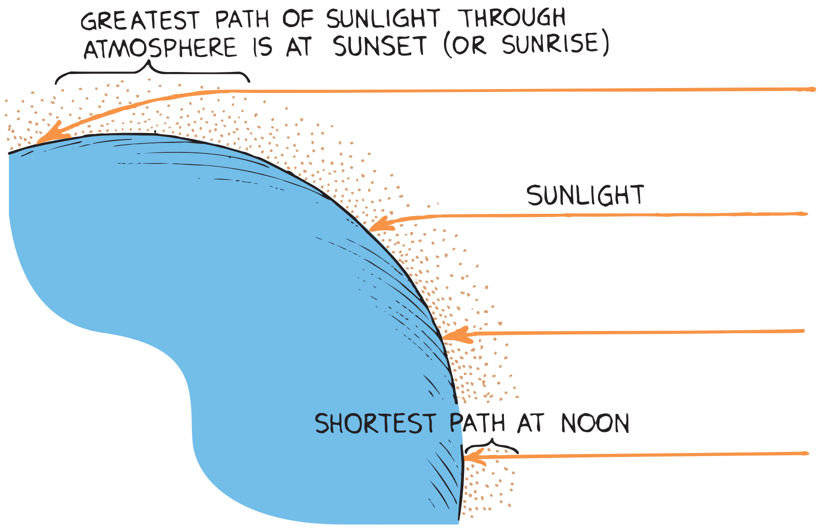


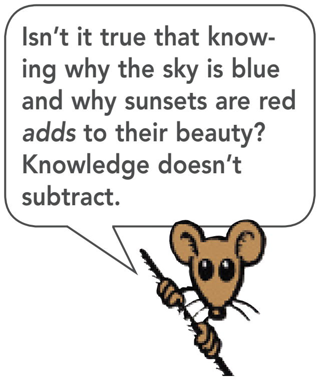
FIGURE 28.18 ▲
By the time a beam of sunlight gets to the ground at sunset, only the lower frequencies survive, producing a red sunset.

At noon sunlight travels through the least amount of atmosphere to reach Earth's surface, as shown in Figure 28.18. Then a relatively small amount of light is scattered from sunlight. As the day progresses and the sun is lower in the sky, the path through the atmosphere is longer, and more blue is scattered from the sunlight. Less and less blue remains in the sunlight that reaches Earth. The sun appears progressively redder, going from yellow to orange. ✓ **By the time a beam of light gets to the ground at sunset, all of the high-frequency light has already been scattered. Only the lower frequencies remain, resulting in a red sunset.** (The sequence is reversed between dawn and noon.)

FIGURE 28.19
The sunset sky is red because of the absence of high-frequency light.

The colors of the sun and sky are consistent with our rules for color mixing. When blue is subtracted from white light, the complementary color that is left is yellow. The subtraction of violet leaves orange. When green is subtracted, magenta is left. The relative amounts of scattering depend on atmospheric conditions, which change from day to day and give us a variety of sunsets.

The next time you find yourself admiring a crisp blue sky, or delighting in the shapes of bright clouds, or watching a beautiful sunset, such as the one shown in Figure 28.19, think about all those ultra-tiny optical tuning forks vibrating; you'll appreciate these everyday wonders of nature even more!



Why do you see the scattered blue when the background is dark, but not when the background is bright? Because the scattered blue is faint. A faint color will show itself against a dark background, but not against a bright background. For example, when you look from Earth's surface at the atmosphere against the darkness of space, the atmosphere is sky blue. But astronauts above who look below through the same atmosphere to the bright surface of Earth do not see the same blueness.

CONCEPT CHECK Why are sunsets red?

think!

If molecules in the sky scattered low-frequency light more than high-frequency light, how would the colors of the sky and sunsets appear? *Answer: 28.9.1*

Distant dark mountains are bluish in color. What is the source of this blueness? (Hint: What is between you and the mountains you see?) *Answer: 28.9.2*

▶ **Teaching Tip** Explain that photographs taken in early morning or late afternoon are "warmer" due to illuminating light composed of more of the lower frequencies.

▶ **Teaching Tip** Question to ponder: Rather than watch the sun moving downward beneath the horizon during a sunset, does an astronomer instead sense Earth rotating away from the "stationary" Sun?

Demonstration

Shine a beam of white light through a colloidal suspension of a very small quantity of instant nonfat dry milk in water, to show the scattering of blue and the transmission of orange. Students will see the beam in the water turn blue as they see the spot of light cast on the wall turn orange.

CONCEPT CHECK By the time a beam of light gets to the ground at sunset, all of the high-frequency light has already been scattered. Only the lower frequencies remain, resulting in a red sunset.

Teaching Resources

- **Reading and Study Workbook**
- **Transparency** *67*
- **Presentation*EXPRESS***
- **Interactive Textbook**

28.10 Why Water Is Greenish Blue

▶ **Teaching Tip** Explain that water absorbs infrared light. It also absorbs some frequencies of visible light, those near the red end of the color spectrum. When red light is taken away from white light, the complementary color cyan is left. Hence the sea looks cyan, or greenish-blue.

▶ **Teaching Tip** Explain that tropical waters have a deeper cyan than cooler waters because warmer water has less air dissolved in it. The greater amount of oxygen dissolved in cooler waters changes their optical properties.

▶ **Teaching Tip** Remind students that a red object illuminated with blue, green, or cyan light absorbs that light and appears black. Deep down in water there is no red left in the light, so things that look red in sunlight look black under deep water. This explains why a red crab and a black crab have the same appearance on the ocean floor.

CONCEPT CHECK Water is greenish blue because water molecules absorb red.

Teaching Resources

- **Reading and Study Workbook**
- **Presentation*EXPRESS***
- **Interactive Textbook**

28.10 Why Water Is Greenish Blue

We often see a beautiful deep blue when we look at the surface of a lake or the ocean, as shown in Figure 28.20. But that is not the color of water. It is the reflected color of the sky. The color of water itself, as you can see by looking at a piece of white material under water, is a pale greenish blue.

FIGURE 28.20 ▶ Ocean water is cyan because it absorbs red. The froth in the waves is white because its droplets of many sizes scatter many colors.

Water is transparent to nearly all the visible frequencies of light. Water molecules absorb infrared waves because they resonate to the frequencies of infrared. The energy of the infrared waves is transformed into kinetic energy of the water molecules. Infrared is a strong component of the sunlight that warms water.

Water molecules resonate somewhat to the visible-red frequencies. This causes a gradual absorption of red light by water. A 15-m layer of water reduces red light to a quarter of its initial brightness. There is very little red light in the sunlight that penetrates below 30 m of water. When red is taken away from white light, what color remains? This question can be asked in another way: What is the complementary color of red? The complementary color of red is cyan—a greenish blue color. In seawater, the color of everything at these depths looks greenish blue.

It is interesting to note that many crabs and other sea animals that appear black in deep water are found to be red when they are raised to the surface. At great depths, black and red look the same. So both black and red sea animals are hardly seen by predators and prey in deep water. They have survived an evolutionary history while more visible varieties have not.

think!

Distant snow-covered mountains reflect a lot of light and are bright. But they sometimes look yellowish, depending on how far away they are. Why are they yellow? (*Hint*: What happens to the reflected white light as it travels from the mountain to you?) *Answer: 28.9.3*

In summary, the sky is blue because blue from sunlight is reemitted in all directions by molecules in the atmosphere. ✓ **Water is greenish blue because water molecules absorb red.** The colors of things depend on what colors are reflected by molecules, and also by what colors are absorbed by molecules.

CONCEPT CHECK Why is water greenish blue?

28.11 The Atomic Color Code—Atomic Spectra

When made to emit light, every element has its own characteristic color. The color is a blend of various frequencies of light. Light of each frequency is emitted when the electrons in an atom change energy states. These energy states are related to the orbits of electrons in the atom. Electrons surrounding the atomic nucleus have well-defined orbits. Another way of saying this is they have well-defined energy levels—lower energy near the atomic nucleus and higher energy farther from the nucleus. When an atom absorbs external energy, one or more of its electrons is boosted to a higher energy level. We say such an energized atom is in an excited state. An **excited state** is a state with greater energy than the atom's lowest energy state. The excited stage is only momentary, for the electron is quickly drawn back to its original or a lower level. When this electron transition occurs, the atom emits a throbbing pulse of light—a photon. Figures 28.21 and 28.22 model this process. ✓ **After an excited atom emits light, it returns to its normal state.**

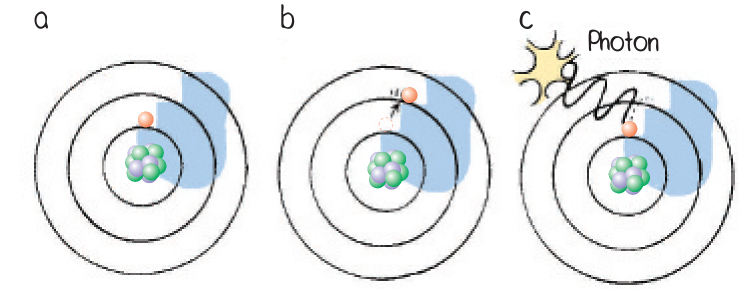
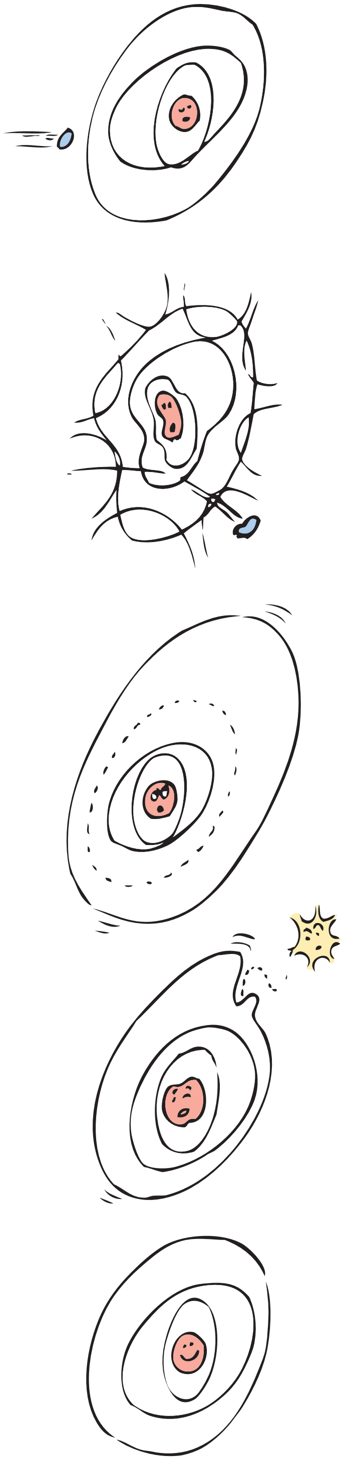


FIGURE 28.22 ▲
a. The different electron orbits in an atom are like steps in energy levels. **b.** When an electron is raised to a higher level, the atom is excited. **c.** When the electron returns to its original level, it releases energy in the form of light.

FIGURE 28.21 ▼
Light is emitted by excited atoms.



28.11 The Atomic Color Code—Atomic Spectra

Key Terms
excited state, spectroscope, line spectrum

The chapter ends with a very brief treatment of atomic spectra tagged on as an extension of color. If you wish to continue further you can cover fluorescence, phosphorescence, and absorption spectra. The topic of atomic spectra leads quite nicely into Unit VI. Jumping from this chapter directly to Chapter 37 has some merit if a short course is desired.

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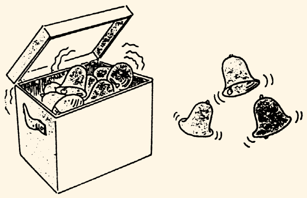
▶ **Teaching Tip** Introduce excitation by holding a book above the lecture table and dropping it. Then hold it higher and drop it again. State that the PE you supplied to the book was converted to KE and then to sound energy. State that the higher you boost the book before dropping it, the louder the sound. State that a similar thing happens in the case of atoms when an electron is boosted to a higher orbit. Just as a screen door that is pushed open against a spring snaps back and produces sound, the displaced electron snaps back to its ground state and produces light.

▶ **Teaching Tip** Explain light emission using the analogy of the emission of sound by tiny bells. If the bells are made to ring all at once while they are crammed together in a box, the sound will be discordant. The same is true of light emitted by atoms that are crammed together in a solid (or liquid) state. There is a spread of frequencies resulting in a wide radiation curve, such as that from the sun shown in Figure 28.7. The light is "smudged," and appears white. (Likewise, the sounding of a wide range of sound frequencies is called *white noise.*) When bells are far apart from one another, however, the sound they emit is pure and unmuffled. Atoms in the gaseous state emit light that is "pure and unmuffled"—the light emitted by glowing atoms in the gaseous state can be separated into discrete pure colors with a spectroscope.



A century ago the chemical composition of the stars was thought to be forever beyond our knowledge—and today we know as much about that composition as we do about Earth's. The light emitted by all things is an atomic fingerprint—it reveals atomic sources. These fingerprints are atomic spectral lines.

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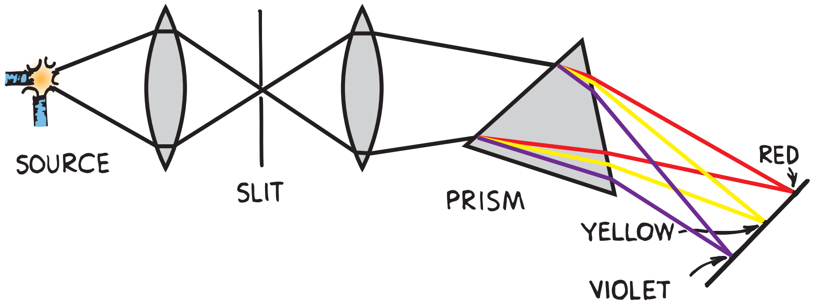
Relating Frequency and Energy The frequency of the emitted photon, or its color, is directly proportional to the energy transition of the electron. In shorthand notation,[28.11.1]

$$f \sim E$$

A photon carries an amount of energy that corresponds to its frequency. Red light from neon gas, for example, carries a certain amount of energy. A photon of twice the frequency has twice as much energy and is found in the ultraviolet part of the spectrum. When many atoms in a material are excited, many photons with many different frequencies are emitted, all corresponding to transitions of electrons between many different levels.

So measuring the frequencies of light in a spectrum is also measuring the relative energy levels in the atom emitting that light. Hence, the frequencies, or colors, of light emitted by elements are the "fingerprints" of the elements.

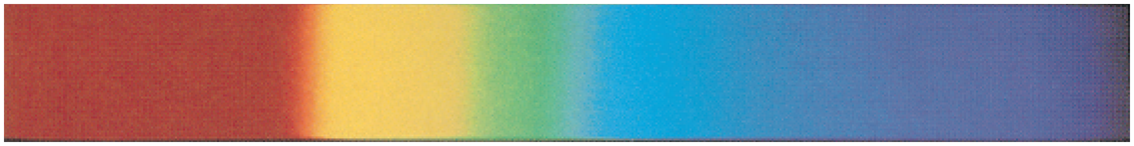
FIGURE 28.23 ▶
A fairly pure spectrum is produced by passing white light through a thin slit, two lenses, and a prism.



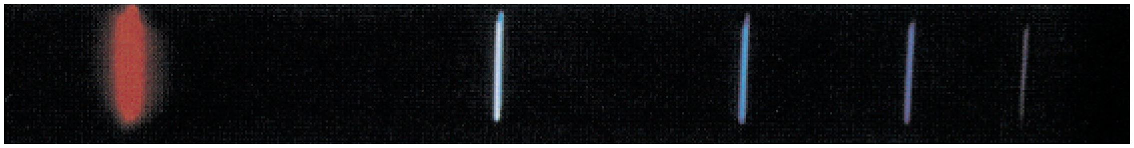
Analyzing Light The light from glowing elements can be analyzed with an instrument called a **spectroscope.** This chapter began with a brief account of Newton's investigation of light passing through a prism. The spectrum formed in Newton's first experiment was blurry because it was formed by overlapping circular images of the circular hole in his window shutter. He later produced a better spectrum by first passing light through a thin slit and then focusing it with lenses through the prism and onto a white screen, as shown in Figure 28.23. If the slit is made narrow, overlapping is reduced, and the colors in the resulting spectrum are much clearer.

This arrangement of thin slit, lenses, and a prism (or a diffraction grating) is the basis for the spectroscope.[28.11.2] A simple spectroscope with a diffraction grating is shown in Figure 28.24. A spectroscope displays the spectra of the light from hot gases and other light sources. (*Spectra* is the plural of *spectrum.*) The spectra of light sources are viewed through a magnifying eyepiece.

FIGURE 28.24 ▲
A spectroscope separates light into its constituent frequencies. Light illuminates the thin slit at the left, and then it is focused by lenses onto either a diffraction grating (shown) or a prism on the rotating table in the middle.

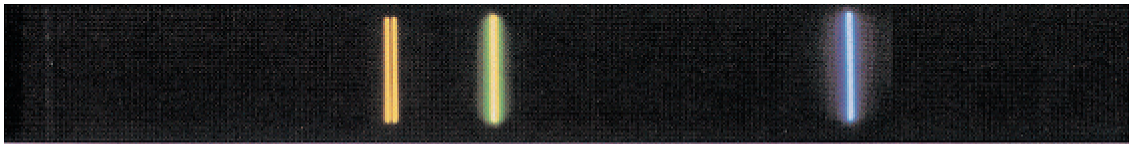


a. incandescent bulb



b. hydrogen

c. sodium



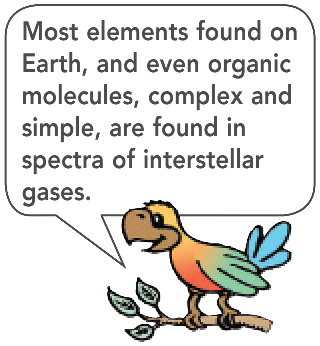
d. mercury

FIGURE 28.25 ▲
a. An incandescent bulb has a continuous spectrum. Each of the three elements **b.** hydrogen, **c.** sodium, and **d.** mercury has a different line spectrum.

When light from a glowing element is analyzed through a spectroscope, it is found that the colors are the composite of a variety of different frequencies of light. The spectrum of an element appears not as a continuous band of color but as a series of lines, as shown in Figure 28.25. Such a spectrum is known as a line spectrum. A **line spectrum** is a pattern of distinct lines of color, with each line corresponding to a frequency of light. The spectral lines seen in the spectroscope are images of the slit through which the light passes. Note that each colored line appears in the same position as that color in the continuous spectrum. A clear spectrum is produced when atoms are made to glow in the gaseous phase. In the solid phase, as in a lamp filament, where atoms are crowded together, the characteristic colors of the atoms are smudged to produce a continuous spectrum.

Much of the information that physicists have about atomic structure is from the study of atomic spectra. The atomic composition of common materials, the sun, and distant galaxies is revealed in the spectra of these sources. Even the element helium, the second most common element in the universe, was discovered through its "fingerprint" in sunlight. The spectrometer is a very useful and powerful tool.

CONCEPT CHECK **What happens to an excited atom after it emits light?**



▶ **Teaching Tip** Give some examples of spectroscope use. Explain how very minute quantities of materials are needed for chemical analysis, how tiny samples of ores are sparked in carbon arcs, and how the light directed through prisms or diffraction gratings can yield precise chemical composition. Note the use of spectroscopes in chemistry and criminology.

▶ **Teaching Tip** Spectrographic studies of clouds of dust between stars in our galaxy reveal more than 120 kinds of molecules. Notably, about half these interstellar molecules are carbon-based organic molecules. How fascinating that atoms that are manufactured in stars then join together to form molecules even in the deep vacuum of space.

Demonstration

Show the spectra of gas discharge tubes with a large diffraction grating (use an 8 1/2-in. × 11-in. sheet of plastic grating available from scientific supply companies). Alternatively, pass out small gratings to your students. Follow this up with individual student viewing of spectral lines of discharge tubes seen with a spectroscope. The spectrum of helium gas is particularly impressive.

CONCEPT CHECK After an excited atom emits light, it returns to its normal state.

Teaching Resources

- **Reading and Study Workbook**
- **Laboratory Manual** *75*
- **Presentation*EXPRESS***
- **Interactive Textbook**

28 REVIEW

Teaching Resources

- Teacher*EXPRESS*
- Virtual Physics Lab *25*
- Conceptual Physics Alive! DVDs *Light and Color*

28 ASSESS

Check Concepts

1. Red, orange, yellow, green, blue, violet
2. No, black is the absence of light and white is a combination of all the colors of light.
3. light
4. It is absorbed.
5. Incandescent light—more lower frequencies; fluorescent—more higher frequencies
6. **a.** Red
   b. Non-red colors
7. Pigments absorb light of specific colors.
8. The human eye is most sensitive to yellow-green.
9. Overlap the red and green.
10. cyan
11. Red, green, and blue
12. Two colors that when added produce white
13. yellow
14. Pigments absorb or "subtract" colors from light.
15. Cyan, yellow, magenta, black
16. Redirection of light in multiple directions
17. high
18. Molecules in the air scatter high-frequency light.

28 REVIEW

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Concept Summary

- Sunlight is composed of a mixture of all the colors of the rainbow.
- The color of an opaque object is the color of light it reflects.
- The color of a transparent object is the color of the light it transmits.
- Yellow-green light is the brightest part of sunlight.
- You can make almost any color at all by overlapping red, green, and blue light and adjusting the brightnesses.
- Every color has a complementary color that when added to it will produce white.
- When paints or dyes are mixed, the mixture absorbs all the frequencies each paint or dye in it absorbs.
- The sky is blue because its component particles scatter high-frequency light.
- A beam of light at sunset contains only the lower frequencies, resulting in a red sunset.
- Water is greenish blue because water molecules absorb red.
- After an excited atom emits light, it returns to its normal state.

think! Answers

28.2.1 The leaves absorb rather than reflect red light, so the leaves become warmer.

28.2.2 The petals absorb rather than reflect the green light. So, the rose appears to have no color at all—black.

28.5 Magenta

28.6.1 Blue

28.6.2 Magenta

28.9.1 If low frequencies were scattered more, red light would be scattered out of the sunlight on its long path through the atmosphere at sunset, and the sunlight to reach your eye would be predominantly blue and violet.

28.9.2 If you look at distant dark mountains, very little light from them reaches you, and the blueness of the atmosphere between you and the mountains predominates. The blueness is of the low-altitude "sky" between you and the mountains.

28.9.3 Distant snow-covered mountains often appear a pale yellow because the blue in the white light from the snowy mountains is scattered on its way to you. The complementary color left is yellow.

Key Terms

spectrum *(p. 555)*
white light *(p. 555)*
pigment *(p. 558)*
additive primary colors *(p. 561)*
complementary colors *(p. 562)*
subtractive primary colors *(p. 565)*
scattering *(p. 566)*
excited state *(p. 571)*
spectroscope *(p. 572)*
line spectrum *(p. 573)*

28 ASSESS

Check Concepts

Section 28.1

1. List the order of colors in the color spectrum.

2. Are black and white real colors, in the sense that red and green are? Explain.

Section 28.2

3. What is emitted by the vibrating electrons of atoms?

4. What happens to light of a certain frequency that encounters atoms of the same resonant frequency?

5. Why does the color of an object look different under a fluorescent lamp from the way it looks under an incandescent lamp?

Section 28.3

6. **a.** What color(s) of light does a transparent red object *transmit*?
   b. What color(s) does it *absorb*?

7. What is the function of a pigment?

Section 28.4

8. Why are more and more fire engines being painted yellow-green instead of red?

Section 28.5

9. How can yellow be produced on a screen if only red light and green light are available?

10. What is the name of the color produced by a mixture of green and blue light?

11. What colors of spots are lit on a television tube to give full color?

Section 28.6

12. What are complementary colors?

13. What color is the complement of blue?

Section 28.7

14. The process of producing a color by mixing pigments is called color *mixing by subtraction*. Why do we say “subtraction” instead of “addition” in this case?

15. What colors of ink are used to print full-color pictures in books and magazines?

Section 28.8

16. What is light scattering?

17. Do tiny particles in the air scatter high or low frequencies of light?

18. Why is the sky blue?

19. Why are clouds white?

Section 28.9

20. Why are sunsets red?

Section 28.10

21. Why is water greenish blue?

19. The mixture of droplet sizes scatters many frequencies.

20. Only low frequencies are not scattered on the long path through the atmosphere.

21. Water absorbs red light.

22. It separates colors.

23. a mixture

24. Each element has its own characteristic spectrum.

Think and Explain

25. Yellow-green tennis balls are highly visible. Our eyes are most sensitive to yellow-green.

26. The black paint absorbs errant light rays, resulting in a better image.

27. yellow—red and green; magenta—red and blue; white—red, blue, and green

28. yellow; all the light is absorbed.

29. Yes, outside there is a full range of colors to be reflected.

30. yellow; yellow; black

31. When blue is subtracted from white light, the emerging color is the complementary color, yellow.

32. If the yellow clothes are illuminated with blue light, no color will be reflected and they will appear black.

33. **a.** Yellow, the addition of red and green
b. Where both shadows overlap, black will result. But the part of the shadow from the green light source that is illuminated with red will appear red. Similarly, the part of the shadow from the red light source that is illuminated with green will appear green.

34. magenta, yellow, and cyan; subtraction

35. The opposite of red, cyan

36. Agree, for the "light mathematics" is correct.

37. Blue illumination produces black. A banana does not reflect blue, which is too far from yellow in the spectrum, so when illuminated with blue it appears black.

38. The reflected color is white minus red, or cyan.

39. We see the laser beam only when it scatters from fog, chalk dust, or some other particles in the air.

40. Rain clouds are composed of large light-absorbing droplets.

41. Orange indicates scattering of low frequencies. At sunset, when the path is longer, very little low-frequency light would get through so the sunset would be bluish.

42. Atoms of the material are heated to glowing, and different kinds of atoms give off their own characteristic colors.

43. Iron spectral lines are found in the solar spectrum.

44. The red will appear black, the green will appear green, and the white will appear greenish blue.

45. In a solid, atoms vibrate with a broad range of frequencies dictated by the temperature. When atoms are far apart in the form of a gas, the emitted light is determined by the structure of the individual atoms. The frequencies are discrete and depend on which elements are present in the gas.

46. Doubling the wavelength of light halves its frequency. Light of half frequency has half the energy per photon. Think in terms of the equation $c = f\lambda$. Since the speed of light c is constant, λ is inversely proportional to f.

28 ASSESS *(continued)*

Section 28.11

22. What is the function of a spectroscope?

23. Does the red light from glowing neon gas have only one frequency or a mixture of frequencies?

24. Why might atomic spectra be considered the "fingerprints" of atoms?

Think and Explain

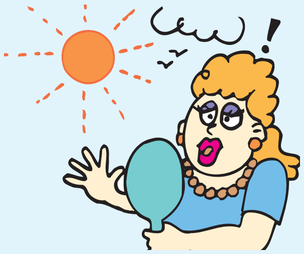
25. What is the color of tennis balls and why?

26. Why are the interiors of optical instruments painted black?

27. On a TV screen, what dots are activated to produce yellow? Magenta? White?

28. Suppose two beams of white light are shone on a white screen, one beam through a pane of red glass and the other through a pane of green glass. What color appears on the screen where the two beams overlap? What occurs if instead the two panes of glass are placed in the path of a single beam?

29. In a dress shop that has only fluorescent lighting, a customer insists on taking a garment into the daylight at the doorway. Is she being reasonable? Explain.



30. What color would a yellow cloth appear to have if illuminated with sunlight? With yellow light? With blue light?

31. A spotlight is coated so that it won't transmit blue from its white-hot filament. What color is the emerging beam of light?

32. How could you use the spotlights at a play to make the yellow clothes of the performers suddenly change to black?

33. A stage performer stands where beams of red and green light cross.
  a. What is the color of her white shirt under this illumination?
  b. What are the colors of the shadows she casts on the stage floor?

34. What colors of ink do color ink-jet printers use to produce the colors you see?

35. On a photographic print, your dearest friend is seen wearing a red sweater. What color is the sweater on the negative?

36. Your friend says that red and cyan light produce white light because cyan is green + blue, and so red + green + blue = white. Do you agree or disagree, and why?

37. In which of these cases will a ripe banana appear black: when illuminated with red, yellow, green, or blue light?

38. When white light is shone on red ink dried on a glass plate, the color that is transmitted is red. What is the color that is reflected?

39. Why can't we see a laser beam going across the room unless there is fog, chalk dust, or a mist in the air?

40. Very big particles, such as droplets of water, absorb more radiation than they scatter. How does this fact help to explain why rain clouds appear dark?

41. If the sky on a certain planet in the solar system were normally orange, what color would sunsets be?

42. What causes the beautiful colors seen in the burning of materials in a fireplace?

43. What is the evidence for the claim that iron exists in the atmosphere of the sun?

44. The only light to reach very far beneath the surface of the ocean is greenish blue. Objects at these depths either reflect greenish blue or reflect no color at all. If a ship that is painted red, green, and white sinks to the bottom of the ocean, how will these colors appear?

45. A lamp filament is made of tungsten. When made to glow, it emits a continuous spectrum—all the colors of the rainbow. When tungsten gas is made to glow, however, the light is a composite of very discrete colors. Why is there a difference in spectra?

46. If we double the frequency of light, we double the energy of each of its photons. If we instead double the wavelength of light, what happens to the photon energy?

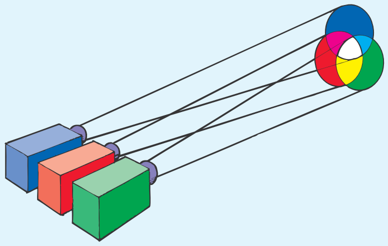
47. We can heat a piece of metal to red hot, and to white hot. Can we heat it until the metal glows blue hot?

48. We see a "green-hot" star not green, but white. Why? (*Hint:* Consider the width of the radiation curve in Figure 28.7.)

49. If you see a red-hot star, you can be certain that its peak intensity is in the infrared region. Why is this? And if you see a "violet-hot" star, you can be certain its peak intensity is in the ultraviolet range. Why is this?

Activities

50. If you have a computer with a color monitor and a color-controlled program available, try the following. Add full-strength red and full-strength green. Note that you produce yellow. Add about two-thirds strength blue and you get a lighter (not darker) yellow. Try full-strength red, blue, and green, and you get white. Can you see that the more light you shed on something, the brighter (that is, closer to white) it gets?



51. Simulate your own sunset: Add a few drops of milk to a glass of water and look through it to a lit incandescent bulb. The bulb appears to be red or pale orange, while light scattered to the side appears blue. Explain why this happens.

47. Continued heating of a red-hot piece of metal will increase the peak frequency into the middle of the visible spectrum, and it will glow white hot. Continued heating will increase the peak frequency into the ultraviolet part of the spectrum, with part of it remaining in the blue and violet. So yes, we can heat a metal until it becomes blue hot. (The reason you haven't seen blue-hot metal is because metal will vaporize before it can glow blue hot.)

48. An incandescent source that peaks in the green part of the visible spectrum will also emit reds and blues, which would overlap to appear white.

49. A star that is red hot has its peak frequency in the infrared, with only some emitted light with frequencies in the lower part of the visible spectrum. A star with peak frequency in the ultraviolet emits enough light in the higher-frequency part of the visible spectrum to appear "violet hot." Again, if it were cooler, all frequencies of the visible spectrum would be present and the star would appear white.

Activities

50. Allow students to experiment mixing colors of different strengths.

51. Incandescent bulbs produce light of each color. The milk transmits the red–orange wavelengths and scatters the blue wavelengths.

Teaching Resources

- Computer Test Bank
- Chapter and Unit Tests