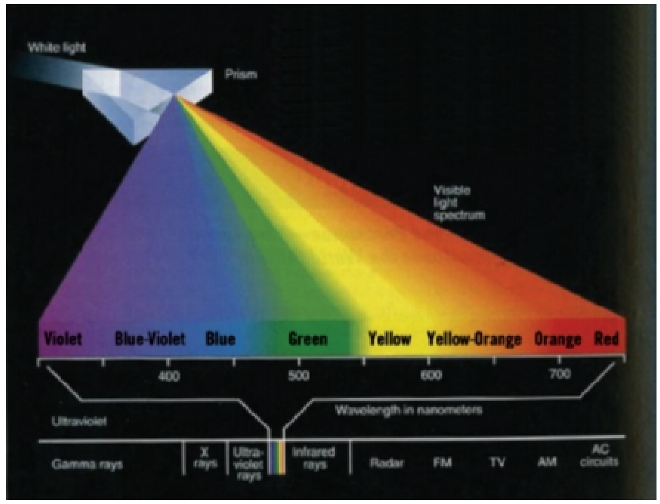
COLOR AND LIGHT

Without light there is no color. Color is a function of light. Isolate a bit of landscape or objects in the distance, then view them first in full sunlight and at nightfall. Your perception of their colors will be very different. The brighter the light, the more able you will be to distinguish among colors; the lower the light, the less able you will be to do so. Depending on the wavelength of the light and the composition of the object's surface, rays of light will be all or partially absorbed by the surface, rendering a perception of a specific **hue.**

The vocabulary we use to discuss color in the visual arts, such as the pigments in paint, is the same as that which describes the physics of light. Red is red whether we are referring to red light or red **pigment,** although they do not necessarily behave in the same way. Mixing light and mixing pigments may achieve dramatically different results.



5.2 Refraction of White Light by a Prism into the Visible Spectrum—the Colors of the Rainbow. Reds have the longest wavelengths and violet, the shortest.

The Science of Light

Sir Isaac Newton (1642–1727), the British physicist of apples-and-gravity fame, designed an experiment to demonstrate that white sunlight consisted of all the colors of the rainbow. He introduced a beam of sunlight through a small hole in a window shade into a dark room. He set a glass **prism**—a triangular solid—in the room in such a way as to allow the stream of light to pass through it. As it did so, the light beam bent upward, separating into a prismatic palette arrayed on a white wall opposite the darkened window. In technical terms, Newton **refracted** the light and recreated the colors of the rainbow, otherwise known as the **visible spectrum** (Fig. 5.2).

The visible spectrum is made up of an array of colors that can be perceived by the naked human eye. Newton described the spectrum in order: red, orange, yellow, green, blue, indigo, and violet—memorized by students for decades with the acronym *Roy G. Biv.* Each of these colors corresponds to a specific region of wavelengths of radiant energy emitted by the sun or an artificial source of white light; the human eye is sensitive to only a narrow band of these wavelengths, measured in nanometers, or billionths of a meter. The "region" of wavelengths from about 625 to 740 nanometers is what we call "red," and the width of the regions across the spectrum varies. Within a region defined by a single color name—red, blue, green, for example—variations of the color appear at toward the borders of that region, so that we perceive a range of reds rather than a single red. Reds have the longest wavelength and violet has the shortest wavelength, about 400 nanometers. Beyond what can be seen by the human eye—again, the visible spectrum—lie wavelengths that are invisible. These include the better-known ultraviolet and infrared waves, as well as gamma rays and x-rays, radio waves, and microwaves.

If people could see colors with slightly longer wavelengths—infrared—warm-blooded animals (and other people) would glow in the dark. This is because warm objects emit infrared waves of light.

Bringing Color Full Circle

It might seem logical that the farther apart colors are along the visible spectrum, the more different they would appear. After all, their wavelengths would be the most different. But Newton noticed that the colors at the distant ends of the visible spectrum—red and violet—actually looked more simi-

hue / Color; the visual sensation created by specific parts of the visible spectrum, enabling us to label it, for example, as red or blue.

pigment / The vehicle for color, be it paint, ink, or other material or substance.

prism / A transparent object with triangular ends, usually made of glass, that separates white light passed through it into the visible spectrum.

refract / To deflect light from a straight path, as by passing it through a medium such as water.

visible spectrum / The segment of the spectrum of electromagnetic energy that excites the eyes and produces visual sensations, arranged in order of wavelengths.

lar to each other than colors closer to them in the middle of the spectrum. Newton toyed with bringing the ends of the spectrum together and thus conceived the color circle. However, he noted that although purple existed in nature, it was missing from the visible spectrum. He found that he could generate purple by overlapping red with violet at the opposite ends of the spectrum. Newton made the center of his proposed color circle white to illustrate his observation that all light, or all wavelengths that had been refracted into color regions by a prism, could be reconverged into white light when passed through another prism.

Newton's color circle served as the precedent for the **color wheel** (Fig. 5.3) and color theory. Early in the twentieth century, innovators on both sides of the Atlantic designed a twelve-point color wheel. The American physicist Herbert E. Ives (1882–1953), who was best known in scientific circles for disputing Einstein's theory of relativity, constructed a twelve-point color wheel based on the three **primary pigment colors**—red, blue, and yellow—from which all other colors of pigment could be derived. **Secondary pigment colors** could be created through the mixing of the primary colors, resulting in green (from blue and yellow), orange (from red and yellow), and violet (from red and blue). Further, six so-called **tertiary colors**—yellow-orange, orange-red, red-violet, violet-blue, blue-green, and green-yellow—could be created through the mixing together of a primary and secondary color. Tertiary colors are also known as *intermediate colors*.

At about the same time, the German artist Johannes Itten (1888–1967) was developing a twelve-point color wheel in Europe. Itten had headed his own art school in Vienna before joining artists and architects like Josef Albers, Marcel Breuer, Walter Gropius, Wassily Kandinsky, Paul Klee, and Mies van der Rohe at the **Bauhaus School**—a school of architecture that taught students to adapt science and technology in their works and promoted the integration of the arts of painting, sculpture, and architecture.

5.3 The Twelve-Point Color Wheel.

Also in the twentieth century, the American Albert H. Munsell (1858–1918) devised a ten-point color wheel, which has become the method of categorizing color used by government agencies such as the National Bureau of Standards and its counterpart in nations including England, Germany, and Japan. Munsell's wheel features five key hues (red, yellow, green, blue, and purple) and five secondary hues (yellow-red, green-yellow, blue-green, purple-blue, and red-purple). In addition, Munsell developed a numerical scale to designate variations in brightness and lightness for individual colors.

ITTEN AND MUNSELL. The color wheel is a method of organizing color relationships. Johannes Itten's twelve-step or twelve-hue model is divided into three categories based on the three primary colors of red, yellow, and blue. These three primaries can be mixed to form the secondary colors of orange (a mixture of red and yellow), green (a mixture of yellow and blue), and violet (a mixture of blue and red). Six tertiary colors can be created from a mixture of a primary color and a secondary color adjacent to it on the color wheel. Thus red and violet create red-violet, red and orange create red-orange, blue and violet create blue-violet, blue and green create blue-green, and so on around a wheel of twelve hues.

color wheel / The traditional wheel for representing colors of pigments, consisting of twelve colors, including the three primary colors of red, yellow, and blue, the secondary colors of orange, green, and purple, and six tertiary colors.

primary pigment colors / Colors of pigments that cannot be created by mixing other colors: red, yellow, and blue pigments. Colors of lights that cannot be created by mixing other lights: red, green, and blue lights.

secondary pigment colors / Colors created by mixing primary colors. The secondary colors of pigments differ from the secondary colors of lights.

tertiary colors / Colors created by mixing primary and secondary colors. The tertiary colors of pigments differ from the tertiary colors of lights.

Bauhaus School / A school of architecture that taught students to integrate science and technology in their works.

5.4 Additive Color Mixtures. You can use a prism to break white light down into its component colors. Similarly, you can add the colors back together again and make white light. Actually, all colors of light can be obtained by mixing, or adding, the three basic or primary colors of light: red-orange, blue-violet, and green. Mixing equal proportions of these three colors creates white light.

Although the Itten wheel is most commonly used, the Munsell color wheel system better predicts the results of paint mixtures. Albert Munsell's Color System starts with a ten-hue model in a wheel configuration. The five basic hues are red, yellow, green, blue, and purple. Mixing any two hues adjacent on his color wheel will yield what Munsell called an intermediate color. Thus red and yellow create intermediate color yellow-red; blue and purple yield purple-blue. Munsell's intermediate hues are yellow-red, green-yellow, blue-green, purple-blue, and red-purple.

Not only did Munsell position the colors such that they more closely represent the results of actual paint mixtures. Munsell is also credited with originating a system of color notation in which a letter and number are assigned to a color to denote not only its hue, but also its value and intensity.

Additive and Subtractive Colors

When all those years as a child you were mixing fingerpaints together on a glossy white sheet of paper, in your mind you probably thought you were adding colors to other colors. Sometimes, two of those colors—like red and blue—made purple; yellow and blue gave you green. You also might remember that the more you blended all of your colors, the more likely it was that you wound up with a muddy brown and wanted to start all over again. You thought that physically adding colors to get another one would work and, until the muddy brown part, it did. But what you probably didn't know is that the colors you were *perceiving* were not the result of the *physical* additive process, but of the *physics* of the subtractive process. **Additive color** is color that is created by mixing colored light. **Subtractive color** is color that is created by mixing pigments.

ADDITIVE COLORS. Additive color refers to rays (or beams) of colored light that, when overlapped or "mixed" with other colored light, produce added (lighter) colors as well as pure, white light (Fig. 5.4). White light results from the overlap of orange-red, blue-violet, and green light or, more simply stated, red, blue, and green light. Because these three colors cannot be derived from the mixing of other colored light, they are called **primary additive colors**. The white spotlight, for example, that you see on stage can be created by the intersection of beams of red, blue, and green light.

When two of these rays of colored light are overlapped, they form lighter colors called **secondary additive colors:** the overlap of orange-red and green create yellow; the overlap of blue-violet and green create indigo (or cyan); and blue-violet and orange-red blend to form magenta (Fig. 5.5).

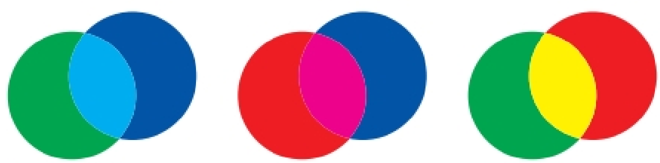
Lighting technicians and artists who use light as a medium do more than place things in the spotlight. They mix the additive primary colors to create the colors you see on your television sets, computer monitors, and smartphone displays. The pixels (dots) under the glass of color monitors and display screens have red, green, and blue *phosphors*—chemicals that produce these primary additive colors when activated. When the monitor or screen is off, it is without color, or black. When all three primary additive colors are illuminated at the same time, the pixels give off white light. Referring once more to Figure 5.5, illuminating green and red phosphors simultaneously yield the perception of yellow light. When the phosphors are illuminated at different inten-

additive color / Color that is created by mixing colored light.

subtractive color / Color that is created by mixing pigments. The subtractive primary colors are red, yellow, and blue pigments.

primary additive colors / Red, green, and blue light, which can be mixed to create lights of other colors. The combination of all three additive primary colors in equal intensities produces white light.

secondary additive colors / The overlap of orange-red and green to create yellow; the overlap of blue-violet and green to create indigo (or cyan); and the blend of blue-violet and orange-red to form magenta.



Green + Blue Light = Cyan **Red + Blue Light = Magenta** **Green + Red Light = Yellow**

5.5 The Overlapping of the Additive Primary Colors. When you mix lights, the result is vastly different from when you mix pigments. For example, mixing green and red lights yields yellow light, not the muddy brown you obtain when you mix green and red pigments.

5.6 Mixing the Three Primary Subtractive Colors. Subtractive color is based on the absorption, or subtraction, of light. The three primary subtractive colors are cyan, magenta, and yellow. Combining all three primary subtractive colors in the right proportions yields black.

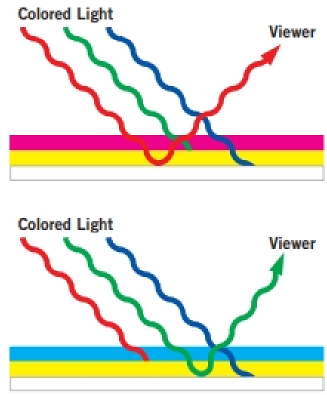
sities, they mix to create any of the colors of the visible spectrum.

SUBTRACTIVE COLORS. Subtractive color refers to the mixing of pigments, dyes, and inks rather than light, and is therefore more relevant to the actual practice of the artist. The process of mixing pigments is called subtractive because the color that is perceived is based on the absorption, or "subtraction," of light. What actually happens is that when you cover a surface with a specific paint color, that layer *absorbs* colors of the spectrum *other than the one that you applied.* So if your paint contains red pigment, your painted canvas reflects wavelengths within the red range and absorbs the others. Your surface will appear "red" to the human eye if it absorbs all wavelengths except for ones between 625 and 740 nanometers.

In sum, the pigment you apply to a surface results in the *subtraction* of all the other colors of the visible spectrum—that is, all of the wavelengths being reflected by the surface except for those that correspond to red. And what about the blank white surface you began with before you were inspired to cover it with red paint? It was reflecting all wavelengths of the visible spectrum. None is being absorbed, or subtracted from the spectrum.

The **primary subtractive colors** are cyan, magenta, and yellow. When combined in equal amounts, the result appears black (Fig. 5.6). When you mix additive colors of light, you obtain *lighter* colors. When you mix subtractive colors of pigment, dye, or ink, you obtain *darker* colors. For example, mixing the relatively lighter colors of magenta and yellow will yield red; the bright blue of cyan mixed with magenta yields a deeper, purplish-blue color.

THE CMYK (FOUR-COLOR) PRINTING PROCESS. The book you are holding in your hands was printed with the **CMYK**—cyan, magenta, yellow, and black (K)—**printing process,** also known as the four-color printing process (see Fig. 5.7). The initial *K* is used for black to avoid any confusion with *B* for blue. CMYK printing is a subtractive process that uses transparent layers of cyan, magenta, and yellow inks to permit light to filter through and reflect the colors that are not absorbed off the printed page. For example, combining magenta and yellow layers will result in the appearance of red on a sheet of paper, because green and blue light will be absorbed by the printed surface and red light will be reflected (Fig. 5.8). Red and blue light are absorbed when cyan and yellow layers are combined; green light is reflected and the color that is perceived is green.



5.8 Transparent Layers of Cyan, Magenta, and Yellow Inks Are Used in CMYK Printing. The viewer perceives the color that is reflected from the surface. In the figure on the top, green and blue light is absorbed by the surface, and red light is reflected. Therefore, the viewer sees red. In the figure on the bottom, red and blue lights are absorbed, and the viewer sees green.

Mixing all three primary subtractive colors in the proper proportions will yield black, so why use black ink in the CMYK printing process? One reason is that combining all three subtractive

primary subtractive colors / Cyan, magenta, and yellow pigments. When combined in equal amounts, the result appears black.

CMYK printing process / The mixing of the three primary subtractive colors (cyan, magenta, yellow, and black) in various proportions to obtain all colors in printed matter.

5.7 The CMYK (Four-Color) Printing Process. The book you are reading is printed in four colors: cyan, magenta, yellow, and black (*K*). Color printers also require four different colors of ink. The four colors are mixed in various proportions to yield literally millions of colors.

^ **5.9 Stanton Macdonald-Wright. *Synchromy in Purple*** (1917) Oil on canvas (36" × 28").

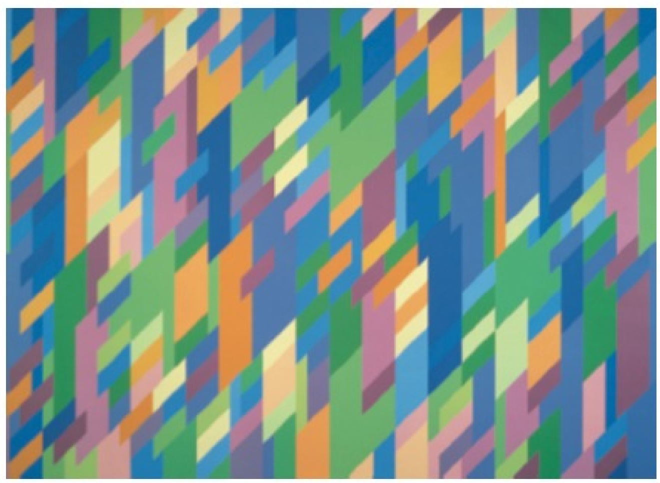
primary colors ought to—at least theoretically—result in the absence of color, or black, as these colors together should absorb all wavelengths. But in practice it may not. The end result likely will be more of a muddy gray or brown if the pigments, to start with, are not absolutely pure. For what is called a truly "rich black," it is better to use black ink. Also, adding small amounts of black ink to color inks is the easiest way to create a spectrum of shades of those colors.

REALITY VERSUS THEORY. Artists who work with light manipulate additive primary colors, but those who mix pigment on a palette and apply it to canvas are working with the principles of the subtractive process. Mixing the additive primary colors of red, blue, and green until the end of time will not produce white; nor will mixing red and green come close to pure yellow. Similarly, mixing pigments of the three subtractive primary colors is unlikely to yield a rich black.

Stanton Macdonald-Wright explored the science of light in his *Synchromy in Purple* (Fig. 5.9), an abstract painting founded in color theory and based on the relationships of color and light. Bits and pieces of the visible spectrum seem to emerge and submerge within vaporizing passages of white light, while shards of magenta, red, green, and violet condense and retreat into velvety shadow. All of the potential of color, light, theory and expression has been united in a single, deliberate, and yet spontaneous work.

Cool and Warm Colors

Cool and *warm* apply, in typical usage, to temperature and so-called cool and warm colors have that association. Just as getting close to the red-orange flames of a crackling fire creates a literal sense of warmth, compositions bathed in yellow, orange, and red convey a feeling of warmth or heat. Plunging into the blue waves after basking in the sun on the beach cools our bodies instantly and walls painted blue have



^ **5.10 Bridget Riley. *August*** (1995) Oil on linen (64 7/8" × 90 1/8").

< **5.11** **Paul Cézanne.** ***Mont Sainte-Victoire Seen from the Bibemus Quarry*** (c. 1897) Oil on canvas (25 1/8" × 31 1/2").

been known to give office workers an unpleasant case of the chills.

When the human eye focuses on color, muscular movements in the eye force warm colors—red, orange, yellow—to advance toward the eye and cool colors—blue, green, purple—to move away from it. Color can thus be used to contribute to the visual impression of depth in a two-dimensional work like a painting.

Bridget Riley's *August* (Fig. 5.10) features some of the optical illusions and perceptual tricks employed by artists of the **Op Art** movement, of which she was a leading figure. The goal in many works in this style was to create a dizzying sense of movement and impression of depth on a static, two-dimensional surface. In *August,* Riley arranged color blocks in a diagonal pattern that cuts across the painting and creates an illusion of movement. The optical effect created by her irregular juxtapositions of warm colors that advance and cool colors that recede keeps the eye from "landing" and the surface dynamic.

Riley's early canvases are more typically black and white. But later in her career, inspired by the color palette of the French Post-Impressionists, she expanded her own to include oranges, blues, and greens like those in Paul Cézanne's *Mont Sainte-Victoire Seen from the Bibemus Quarry* (Fig. 5.11). Color provides an important spatial cue in Cézanne's painting: the warm reddish and ochre tones of the quarry stone in the lower half of the painting visually advance to the foreground and the mountain peak—which appears in so many of Cézanne's landscapes—recedes into the background by virtue of its blue, gray, and purple hues set against a mottled blue sky.

TRY THIS

Take an image that you have somewhere in your home—a photograph, drawing, magazine cutout, or even a digital image. Draw a line down the center of the image, dividing it into right and left halves. On the left half, take either a piece of chalk, a thin layer of paint, or the paint bucket tool in Photoshop and apply a thin wash of a cool color on the surface. Then apply a thin wash of a warm color to the right half. Cover one side at a time and pay close attention to how the different hues affect the feeling that the image conjures. Then look at both sides together. How do these different hues influence or interact with each other when placed side-by-side?

Op Art / A style of art begun in the 1960s that creates the illusion of vibrations through afterimages, disorienting perspective, and the juxtaposition of contrasting colors; also called Optical art or Optical painting.

5.12 Henri Matisse. *View of Collioure.* (1905) Oil on canvas (23 1/4" × 28 3/4").
© 2014 Succession H. Matisse/Artists Rights Society (ARS), New York.

The opposite spatial effect was achieved in another French landscape, painted only a decade after Cézanne's Bibemus canvas. In *View of Collioure* (Fig. 5.12), Henri Matisse reversed Cézanne's foreground–background palette choices, thereby precluding the visual impression of depth. The warm colors that he used in the foreground and background of the composition naturally advance, and the cool colors that he placed in the middle ground recede. Our daily visual experiences lead us to expect that objects in the lower part of the visual field (for example, on the ground) tend to be closer than those in the upper part of our visual field (for example, distant buildings or mountains, the horizon, the sky). Matisse's painting creates a tension between the brain, which wants to make sense of the location of the houses, water, and sky—and the eye muscles, which have to struggle to keep them in their assigned strata.

PROPERTIES OF COLOR

Color is discussed in terms of its physical properties and visual perceptual properties. Its physical properties—such as wavelength and light absorption and reflection—can be measured with scientific instruments. The perceptual properties of color, on the other hand, are based on the interactivity of light receptors—cone cells—in the human eye with the visible light spectrum. Stimulation of these cells leads to the perception of color.

The three key perceptual properties of color are hue, **value,** and **intensity.** These terms describe color in any vehicle—in paint, inks, or other materials and substances.

Hue

Simply defined, hue is pure, unadulterated color—as it appears on the color wheel. Our perception of hue is connected to the eye's sensitivity to specific parts of the visible spectrum—red, yellow, blue, and green—sometimes referred to as "unique hues." (Green is not a primary additive color, but we perceive it to be a pure, unique color.) These hues, however, can be expanded to create any number of variations and gradations of that hue. Black and white are colors, or pigments; they are not on the visible spectrum, however, and therefore are not considered hues. Black, white, and gray are considered **neutral colors.**

Value

As stated, *value* refers to the lightness or darkness of a hue—its degree of luminosity. The value of a hue can be altered by adding black or white to that hue. The addition of black results in

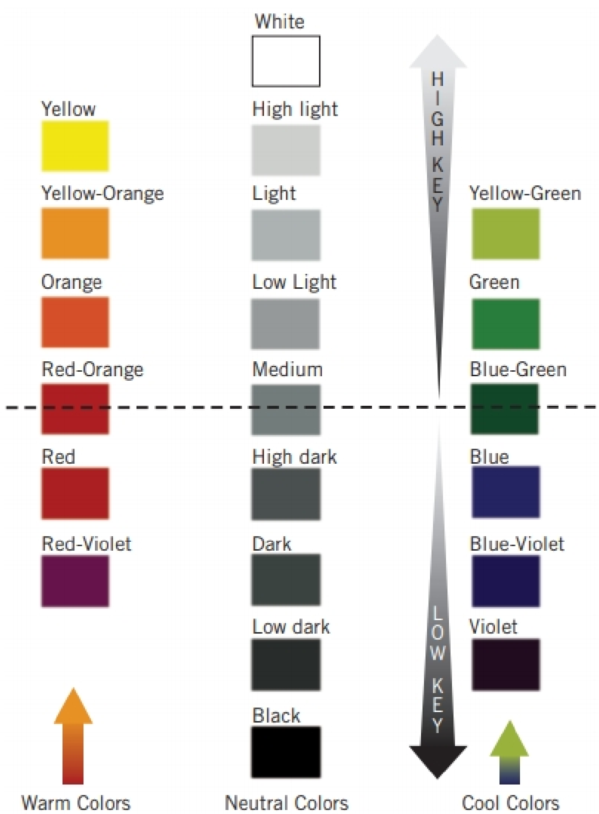
value / The lightness or darkness of a color.

intensity / Brightness of a color. Pure colors, such as unmixed pigments, are most intense.

neutral colors / Colors mixed with gray and, sometimes, also weakened in intensity.

TRY THIS

It is important for artists to develop their visual memory. John Sloan, a painter and renowned art educator, thought it was good practice to draw everything that you draw from a model from memory as well. The next time you are walking or driving from one place to another, pay attention to the colors that you encounter along the way. At the end of the day, try to record those colors on a piece of drawing paper using paint, colored chalk, or oil pastels. Which colors have made the greatest impression in your memory? How would you describe them in terms of hue, value, and intensity?



5.13 Color Values Relative to the Gray Scale.

shades of that hue; adding white produces **tints** of that hue. Mixing gray with a color can create a variety of **tones.** Maroon or burgundy are shades of red; pink is a tint of red. Whereas hues are few in number, tints and shades of hues are numerous. The human eye can perceive at least forty tints and shades of any one color.

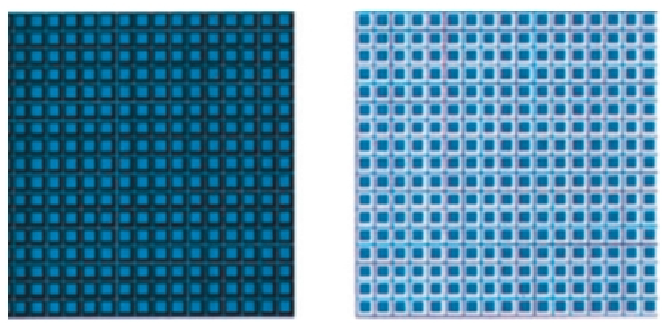
Colors have different values because each one in the visible spectrum reflects a different quantity of light. Yellow and orange are called high-value, or high-key colors. This is because they reflect a greater amount of light than low-value or low-key colors such as blue or violet. You can observe this yourself by comparing the values of the colors of the visible spectrum against a scale of neutral values ranging from white to black (Fig. 5.13). The medium gray matches the intensity of red-orange and blue-green. Those hues that sit above the median gray have higher values or reflect a greater amount of light; those that fall below have lower values and reflect lesser amounts of light.

The value of a pigment color can be changed by adding white or black (as already noted), by mixing a high-value color with a low-value color, or by diluting or thinning a color with medium or solvent. High-key colors will become low-key colors if enough black is added to them; low-key colors become high-key colors depending on how much white is added. Figure 5.14 illustrates what happens to the value of a color when the eye "visually mixes" it with black or white. Black and blue together create the perception of a low-key value of blue; white mixed with the same blue create the perception of a high-key value.

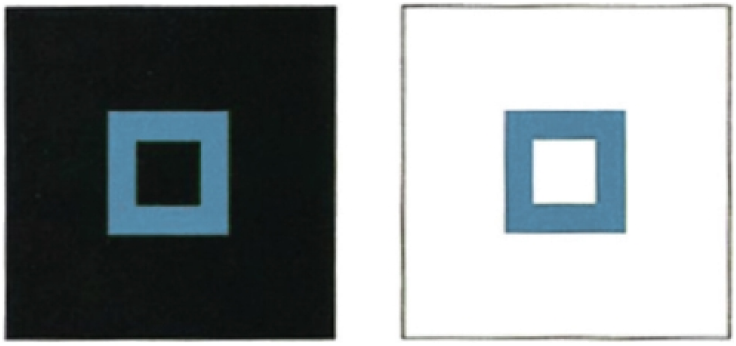
shade / A low value of a color, created by the addition of black to a hue.

tint / A high value of a color, created by the addition of white to a hue.

tone / A variety of values created by the addition of gray to a hue.



5.14 Visual Mixing.



5.15 Color in Different Value Contexts.

The perception of the value of a color is dependent on that which surrounds it. Figure 5.15 illustrates the visual sensations of the same colors against different backgrounds. The center blue square appears more luminous and of higher value when seen against black than it does when seen against white. This principle is the foundation of much of James Turrell's light works (Fig. 5.16).

Intensity, Chroma, and Saturation

Intensity, **chroma,** and **saturation** are synonymous terms that describe the brightness or dullness of a color. A color is most intense or most saturated when it is most pure—like the color that is perceived when a beam of light is

chroma / Another term for the intensity of a color.

saturation / Another term for the intensity of a color.

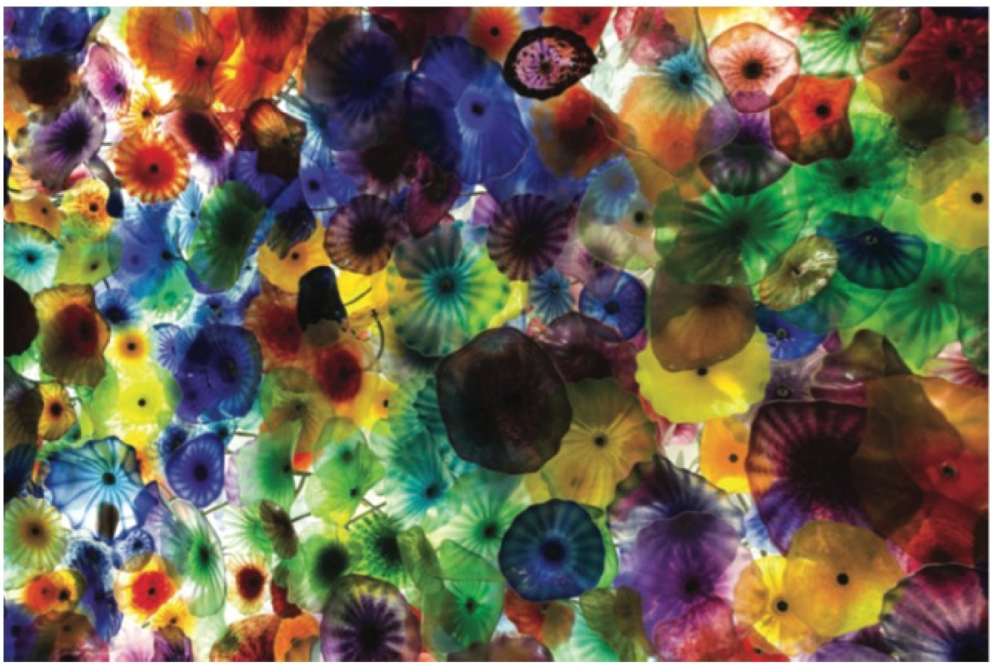
5.16 James Turrell with Future Scape Architects. *House of Light.* Niigata, Japan. On the left is an interior view of the traditional tatami room with its Turrell-designed retractable roof. On the right is the House of Light at twilight.

TRY THIS

Set up a camera outside to take photos of a landscape throughout the duration of a sunset. Make sure you start early enough and end late enough to capture the sunset in its entirety. Take one photo per minute. Make sure that the frame stays the same for each photo. Later, assemble all of your photographs in chronological order. Examine how the saturation changes over time. Pull the first photograph and the last one and place them side-by-side. Notice the shift in color intensity. Finally, using all of the photographs, make a large grid or a collage that portrays the passing of time as witnessed through the changing colors.

5.17 Hue, Value, and Intensity.

refracted through a prism, or the color of pure pigment that has not been mixed with black or white. When colors are mixed with black or white or their complement their intensity is affected, as is their value. Colors can have similar values but different intensities—different degrees of brightness (Figs. 5.17 and 5.18).



5.18 Dale Chihuly. Glass Flowers (1998) Bellagio Casino, Las Vegas, Nevada.