Part I Color Foundations

Three basic elements are required for an appreciation of color: a light source, an object, and a viewer. This part begins with the fundamentals of color observation. We describe the physiology of the eye and how light imparts color to objects, as well as the psychological and cultural factors involved in perception. These factors in turn affect whether an artist chooses to use local, optical, or arbitrary color. Next we examine the different color systems and "wheels," along with their application to different media.

The science and psychology of color have fascinated thinkers for centuries. On our historical journey, we meet such individuals as Leonardo da Vinci, Sir Isaac Newton, and Josef Albers. Their influence on the discipline of color today remains strong.

Finally, we look at coloring agents—additive and subtractive color mixing, pigments, dyes, binders, grounds—and discover how color is employed in the art of four-color printing and photography.

Opposite: Odilon Redon, *The Golden Cell (Blue Profile)* detail, 1892 (see also fig. 1.8).

CHAPTER 1

What Is Color?

More than any other element of design, color has the ability to make us aware of what we see, for nothing has meaning without color (here we extend the meaning of color to include black and white). Try to describe the sky, for example, without referring to color—it is very difficult.

Color defines our world. It is usually seen before imagery. Our eyes are attracted to color to such an extent that the color of an object is perceived before the details imparted by its shapes and lines. At first glance we do not see the different species of trees present in a summer woodland, but rather see the prepon-

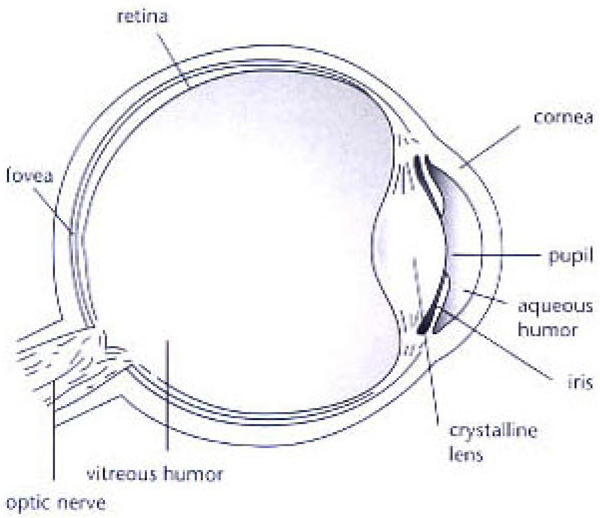
1.1 Henri Matisse, *The Red Studio*, 1911. Oil on canvas. 71¼ x 86¼ in (181 x 219.1 cm). The Museum of Modern Art, New York. Mrs. Simon Guggenheim Fund. Our initial impression is of an abundance of red color. We must take a second look to determine the objects in *The Red Studio*. This is an example of how color is seen before imagery, and in the hands of a master like Matisse it is a case of the exception proving the rule.

derance of green. The artist, architect, and designer, however, are generally concerned with having color and imagery perceived simultaneously. An art work, be it fine or commercial, works best when its color usage allows the viewer to see the content of the piece (both color and imagery) together. When this is accomplished a work's message is conveyed immediately, without a "second look" on the part of the viewer (**fig. 1.1**).

Color can also be described by two very different methods or points of view—objectively, by referring to the laws of chemistry, physics, and physiology; and subjectively, by referring to the concepts found in psychology. Similarly, our perception of objects depends both on physical factors—such as their actual **hues** (the name of a color: red, yellow, blue), their lightness and darkness in relationship to surroundings—and on more psychological and cultural factors.

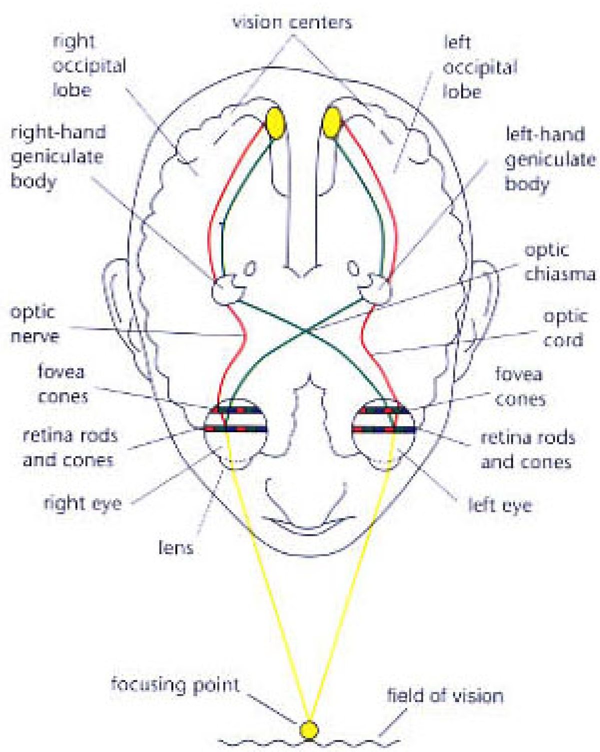
PHYSIOLOGY

Physiologically color is a sensation of light that is transmitted to the brain through the eye. Light consists of waves of energy, which travel at different **wavelengths**. Tiny differences in wavelengths are processed by the brain into a myriad nuances of color, in much the same way as our ear/brain partnership results in our interpretation of sound. Sound lets us interpret our auditory language; color lets us interpret our visual language. Because each of us is unique, our eye/brain reactions differ. Thus, when we speak of color, we cannot speak in absolutes but must resort to generalizations. These are sensations that *seem* to happen to all of us.



1.2 The human eye. We distinguish the world of color after light passes through the cornea and pupil and strikes the retina, which subsequently passes messages to the fovea from where they are transmitted to the brain.

As light passes into the eye (**fig. 1.2**) it comes in contact with the covering near the back of the eye known as the **retina**. The retina is made up of layers of different cells, including those known as **rods** and **cones**. The function of the rods is to allow the brain to see dimly lit forms. They do not distinguish hue, only black and white. The cones, however, help us to perceive hues. The cones in the eye only recognize red (long wavelengths), blue-violet (short wavelengths), and green (middle wavelengths), and relay these color messages to the cones of the **fovea**, an area at the center of the retina, whose cones transmit to the brain. The brain then assimilates the red, blue-violet, and green impulses and mixes them into a single message that informs us of the color being viewed. When we see red, for example, this is because the red-sensitive cones are activated while the green and blue-violet ones are relatively dormant. Yellow is the result of the green-sensitive and red-sensitive cones being activated and mixed while the blue-violet cones remain comparatively inactive (**fig. 1.3**).

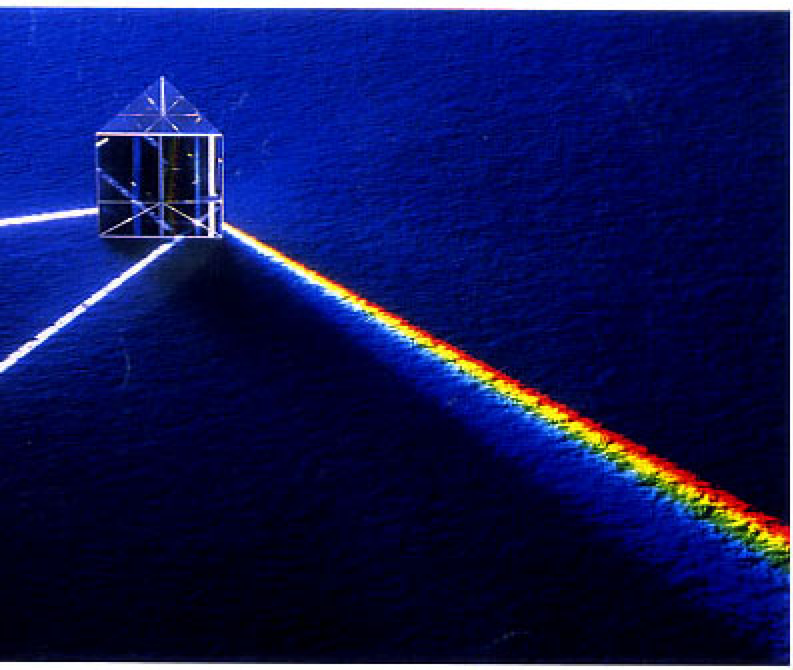


1.3 The eye/brain processing the color yellow. The yellow sensation is passed through the lens of the eye and is converted in the retina to the light components of red and green. From the retina these components are conveyed to the fovea, which transmits them to the brain. The brain mixes the red and green messages to create the yellow that we see.

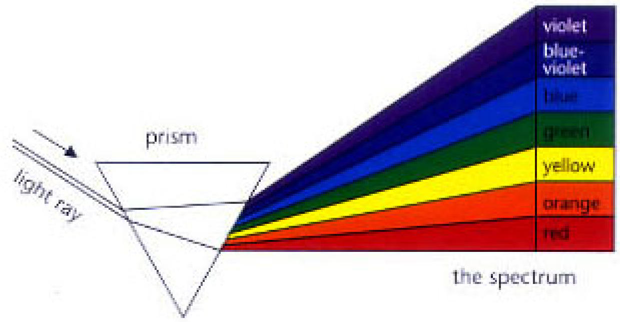
HOW LIGHT GIVES OBJECTS COLOR

The great physicist and mathematician Sir Isaac Newton (1642–1727) was a pioneer in studying light under laboratory conditions to provide a logical framework for understanding color (see page 13). His early research into color phenomena resulted in his discovery that sunlight is composed of all the colors in the spectrum (**figs. 1.4, 1.5**). Using a ray of sunlight directed through a prism, Newton observed that the ray of light was bent, or refracted, and the result was an array of projected colors, each with a different range of wavelengths, in the following order: red, orange, yellow, green, blue, indigo, and violet. This array, the constituents of light, is known as the **visible spectrum**.

When light strikes a surface, certain wavelengths are absorbed and others are reflected (bounced back) by its **pigments**, or coloring matter. This process gives the surface its color. For example, we see red when only the red wavelengths are reflected off the surface of an object, such as a red apple, and the remaining wavelengths are absorbed. Different combinations of reflected wavelengths form all the observed colors. When all the wavelengths are reflected off a surface and mixed, the result is white. (White light is that light that we perceive as daylight at noon.)



1.4 The spectrum generated by light refracted through a prism. A close examination of the seven major colors of the spectrum also reveals several graduated ones between them. For example, the human eye can detect red-orange between red and orange, and blue-green between blue and green.



1.5 The visible spectrum. Of the seven lightwaves, violet has the shortest wavelength and red the longest.

FACTORS IN PERCEPTION

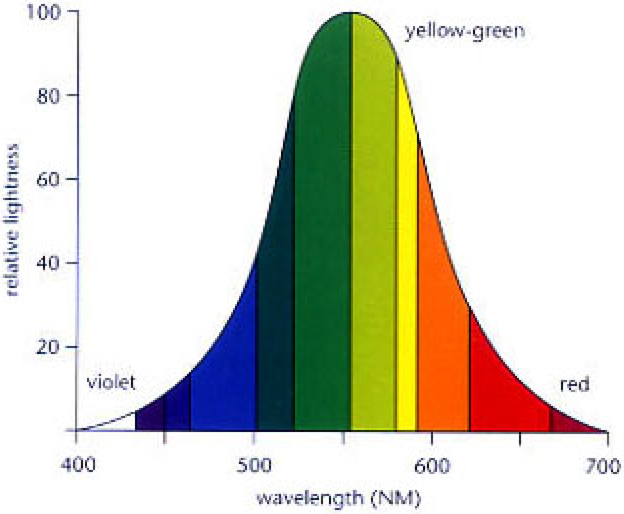
There are many factors affecting our perception of a color, such as the surroundings of the object, its surface texture, and the lighting conditions under which it is seen. How much of a color is used, whether it is bright, dull, light, or dark, and where it is placed in relation to another color are also crucial factors in our perception.

Media and Techniques

Our perception of color in works of art is strongly affected by the type of medium used. Painting alone offers a myriad of different types of media, such as oil, acrylics, and water, that affect our perception of color. We must also take into consideration the type of support employed—canvas, board, or paper, and so on—and what grounds are used, such as **gesso** or primer. Even the brands of paint can provide differences, because of the mediums used for their mixture. How does a pencil line or sketch affect the visual perception of color in a watercolor painting? The textile artist works with a vast array of yarns and fibers, each imparting its unique qualities of sheen and **texture**. Ceramic glazes can result in an overlapping of colors that changes our perception of the piece. We can also experience the same types of color variations in printmaking.

Eye and Brain

The human eye in combination with the brain's reaction tells us how to distinguish the type of color being seen, as well as its relative purity and lightness. But memory also exerts an influence. Most of what we see is based on the memory of a color—when and how we have experienced it before. In addition, certain colors are perceived more easily than others. Yellows and greens are seen before other hues, while red and violet are the most difficult to perceive. If we take



1.6 The perception curve. The yellow and green wavelengths register highest on the relative lightness axis. Someone with normal vision perceiving colored lights of equal energies will register the yellow-green segments of the spectrum first, because they appear brighter than all the other ones.

another look at the hue order of the visual spectrum, we see that a perception curve is formed, with the yellow and green hues at the curve's height and red and violet forming its lower extremities (**fig. 1.6**).

Psychology and Culture

Memory, experiences, intelligence, and cultural background all affect the way a color's impact can vary from individual to individual. This is not to say that the color will be perceived differently, but that that perception will *mean* different things to different people. Let's say we have black—is it the color of death? Maybe in most Western cultures, but not in China and India, where white is regarded as a symbol of death. In America and many Western cultures the bride usually wears white and white is deemed a bridal or wedding color. In China, however, the bride is attired in red. The mailbox on the streets of the United States is blue, but in Sweden the mailboxes are red. The American tourist in Sweden has a more difficult time finding a site to mail those postcards home because of the color change from the familiar blue to red.

LOCAL, OPTICAL, AND ARBITRARY COLOR

The quality of light further determines the quality of any color that we see. A red barn in brilliant noon sunlight will appear red, but a different red than one we would observe at sundown or on a rainy day. Armed with this knowledge, artists, architects, and designers can influence the color sensations of those who view their work. They may use color in three ways to impose these sensations: local or objective color, optical color, and arbitrary color. **Local color** is the most natural. It reproduces the effect of colors as seen in white daylight, exactly as we expect them to be: blue sky, red barn, and green grass. When the artist has a highly realistic style, the composition is rendered in exact colors and values (**fig. 1.7**). **Optical color** reproduces hues as seen in

1.7 Ferrari F50, 1996. The local color of this car stands out on a bright, cloudless day.

1.8 Odilon Redon, *The Golden Cell (Blue Profile)*, 1892. Oil and colored chalks, with gold, $11\frac{7}{8} \times 9\frac{3}{4}$ in (30.1 x 24.7 cm). British Museum. Bequest Campbell Dodgson. The Symbolist painter Redon uses a gold background in order to suggest a Byzantine mosaic of the fourteenth or fifteenth century, which typically employed this color. However, he chooses to interpret the woman's dreaming face in arbitrary color, associating her in his fantasy with the Virgin Mary, who is traditionally rendered in blue.

1.9 Thomas Cole, *The Course of Empire: The Savage State*, 1834. Oil on canvas, 39¼ x 63¼ in (99.7 x 160.6 cm). The New York Historical Society, New York. Weather conditions determine subtle changes in the optical color of this landscape. The effects of sunlight originating beyond the left of the painting can be seen tinging the light-green leaves in the left foreground, while gray thunderclouds serve to darken the landscape in the central and right-hand areas.

lighting conditions other than white daylight: in the rain or thunder (**fig. 1.9**), at sunset, or in indoor lighting. Again the composition is rendered in a somewhat naturalistic way. **Arbitrary color** allows the artist to impose his or her feelings and interpretation of color onto the images (**fig. 1.8**). Here, natural color is abandoned for the artist's choice. A gray stone bridge may be executed in warm oranges and beiges if the artist wants the bridge to impart a feeling of vitality and warmth. Arbitrary color is most often seen in twentieth-century art, especially among the Expressionists and Fauves, whereas local and optical color are employed in more realistic styles.

CONCEPTS TO REMEMBER

- Color is usually seen before imagery.
- The physiology of the eye and the brain's reaction enable us to perceive light as different colors.
- The color imparted by an object is produced by the mixture of wavelengths reflected from its surface.
- Our perception of the color of an object is dependent upon several factors, such as illumination, media, techniques, quantity, relationship to other colors present, memory, and culture.
- Most color usage employs one of three aspects of color—local color, optical color, or arbitrary color—and any of these can be manipulated by users to create desired reactions in the viewer.

Exercises

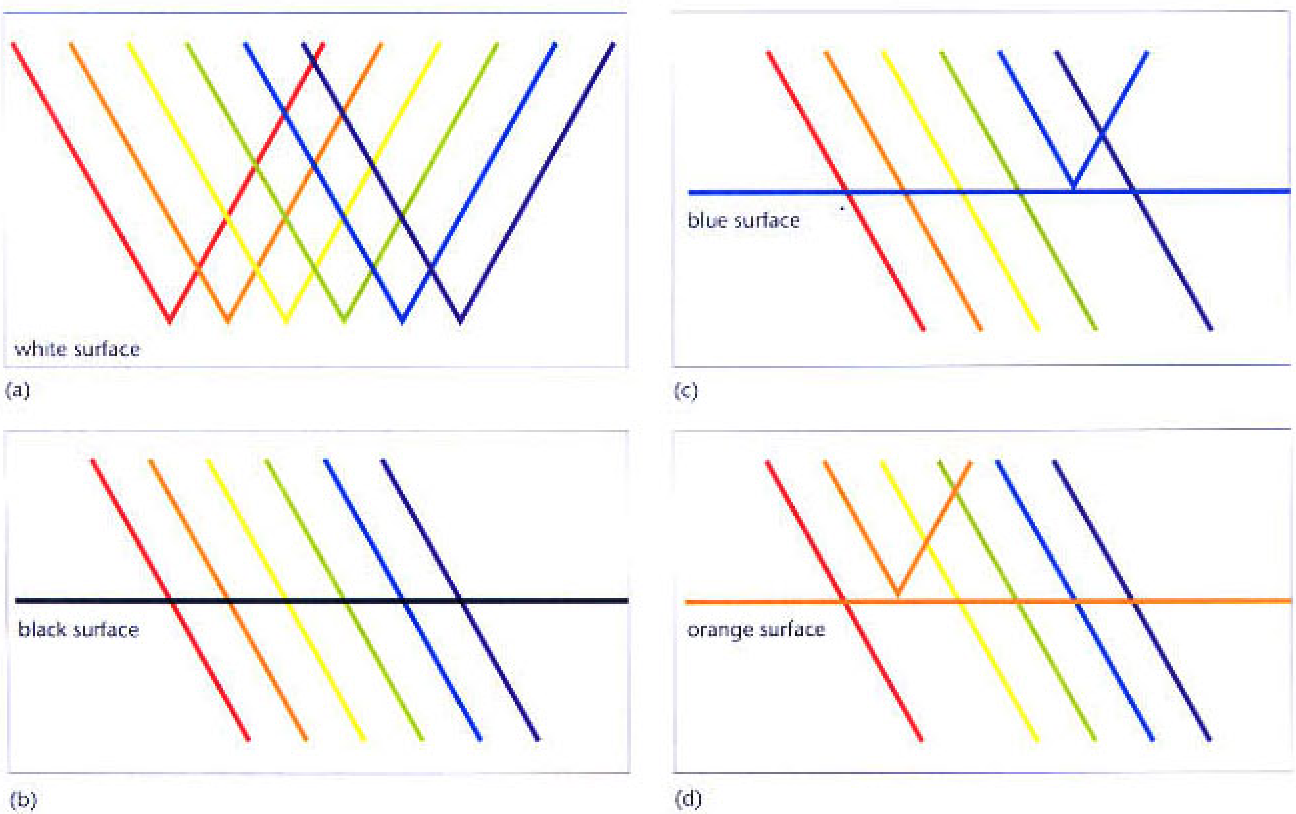
1. Observe an object under different lighting conditions, and, if you can, take some color photographs. How do the different conditions affect its color?
2. Collect and label pictures (magazine photographs are good) showing local, optical, and arbitrary color.

CHAPTER 2

Color Systems and Color Wheels

Over the centuries colors have been mixed according to three different systems. **Subtractive color** is the process of mixing pigments together, such as we see in painting. As we saw in chapter 1, the pigments in an object enable it to absorb some light waves and reflect others (**fig. 2.1**). When these pigments are blended, more light is absorbed and less is reflected—hence the term "subtractive." By contrast, the colors in light are additive—the more they are mixed with other colors, the lighter they become. **Additive color** is the process of mixing colored light, such as in theatrical lighting or television. The **partitive color** system is based on the reaction that colors have when they are placed next to each other. Bear in mind that all colors are seen in relation to other colors rather than in isolation.

Color wheels are color arrangements or structures that enable us to organize and predict such color reactions and interactions. As you will see, just one wheel or system may not satisfy all our needs. For example, the painter uses subtractive color (to create various colors of paint) and partitive color (to create color reactions according to where the paint colors are placed). The photographer uses additive color (to create the colors or **values**—lightness or darkness—within the photograph) and partitive color (to impart reactions and interactions between the photographic imagery). The textile artist uses subtractive color (to create colors of yarn and textiles by dyeing) and partitive color (to impart reactions and interactions that occur from color placement). It becomes obvious that all art media use partitive color, and that the specific materials employed within each medium can be either additive or subtractive. Each artist must determine which wheel or wheels best satisfy the needs at hand.



2.1 The surface absorption of light rays. A white surface (a) will reflect all light rays that strike it while a black surface (b) will absorb them. A colored surface (c) and (d) will reflect the same colored light ray striking it but absorb other colors.

THE PIGMENT WHEEL

The mixing or **pigment wheel** is the basis for working with subtractive color; it imparts information about the reactions colors have when they are actually mixed (**fig. 2.2**). Its **primary colors** are red, yellow, and blue, which are used in combination to form the other hues. The term "primary" tells us that this is a color that cannot be obtained by mixing. When two primary colors are mixed together a **secondary color** (or intermediate color) is the result of the mixture. Yellow and blue mixed together result in green. Red and yellow mixed together produce orange, and a mixture of red and blue results in violet (sometimes called purple). Thus the secondaries are green, orange, and violet. When a primary color and an adjacent secondary are mixed, **tertiary colors** are the result:

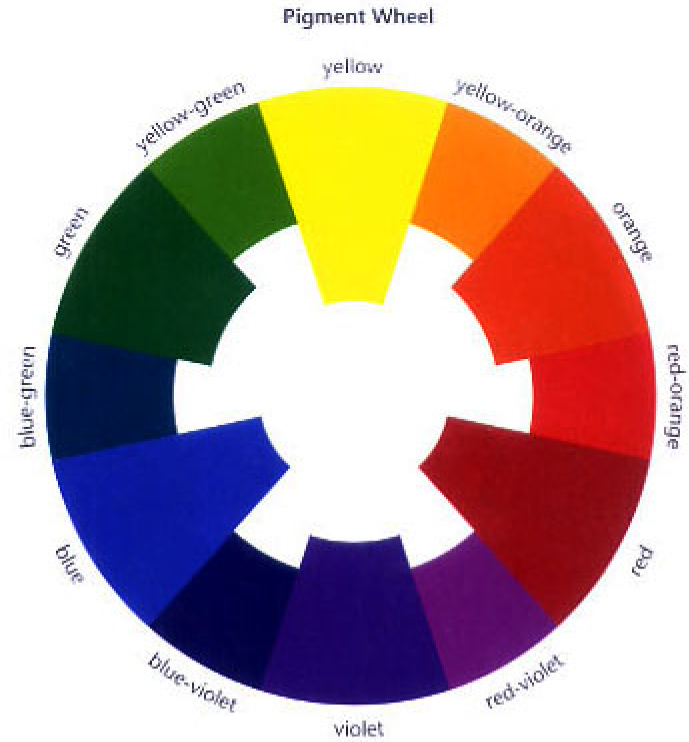
- red + orange = red-orange
- orange + yellow = yellow-orange
- yellow + green = yellow-green
- green + blue = blue-green
- blue + violet = blue-violet
- violet + red = red-violet.

When using this wheel keep in mind that red, yellow, and blue cannot be obtained by mixing pigments, and that when these three primary pigments are combined a muddy black is the result. Imperfections in the pigments mean that the black is not pure, as it should be in theory. Also, note that the secondary and tertiary hues are not equal mixtures of their components. Mixing equal amounts of yellow and blue pigments together will result in a green that is more yellow-green than green because yellow is stronger than green.

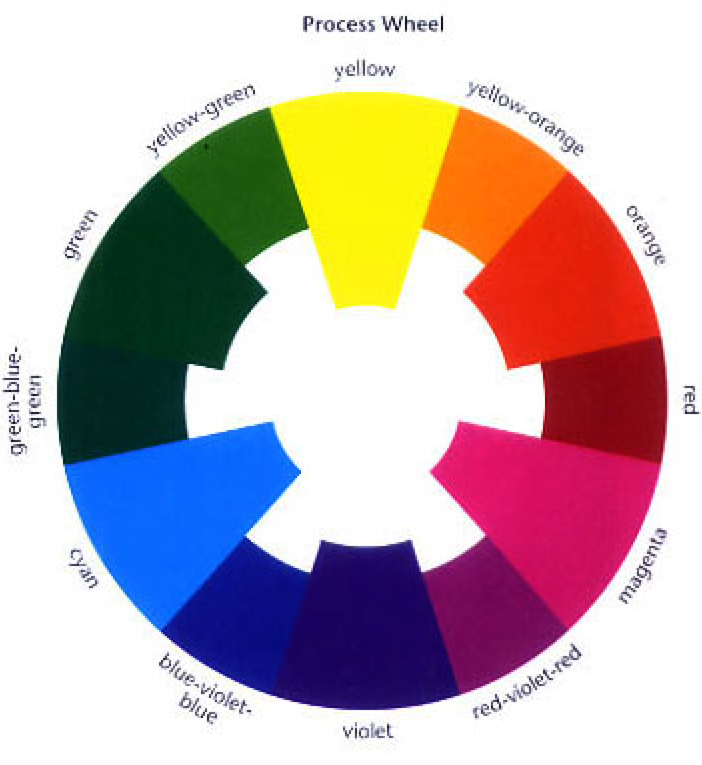
THE PROCESS WHEEL

In contrast to the pigment wheel, the **process wheel** gives us three basic primaries—yellow, magenta, and cyan—that do, upon mixing, result in purer hues (**fig. 2.3**). This primary arrangement is the standard employed in color printing and photography as well as pigment (usually ink) manufacture. A look at the colors used shows a very luminous and bright yellow, an intense magenta that is red though leaning toward violet, and a cyan that is blue but tending toward green. When we take equal parts of these primaries and mix them, the following secondary hues result:

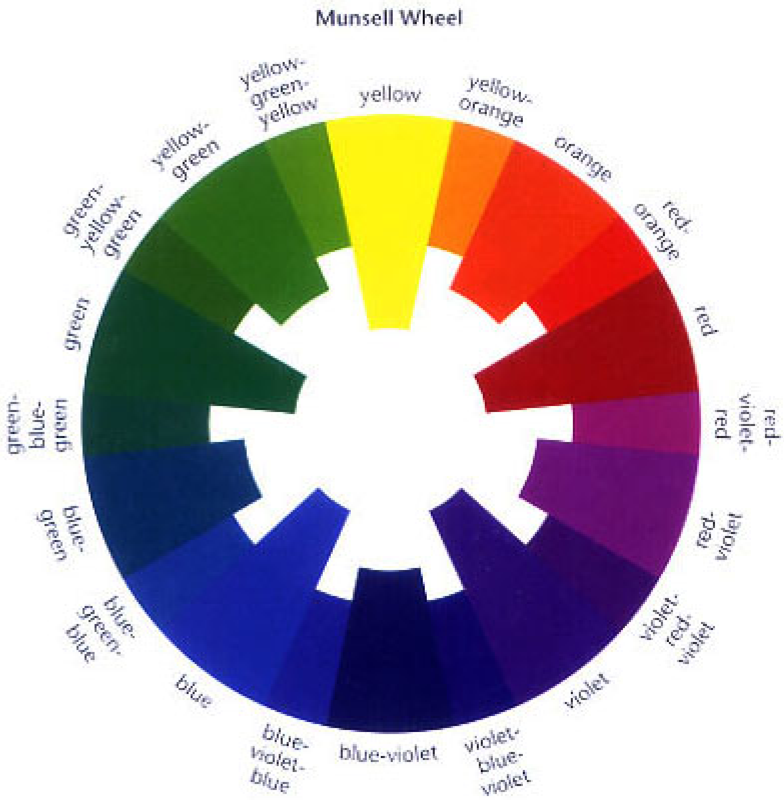
- yellow + cyan = green
- cyan + magenta = violet
- magenta + yellow = orange.



2.2 The pigment wheel. Mixing two primaries from this twelve-step subtractive color wheel produces a secondary. Mixing a primary with a neighboring secondary results in a tertiary.



2.3 The process wheel. The primaries and tertiaries in this twelve-step subtractive color wheel are different from those in the pigment wheel, but the secondaries are the same.



2.4 The Munsell wheel. This twenty-step partitive color wheel consists of five primaries, five secondaries, and ten tertiaries.

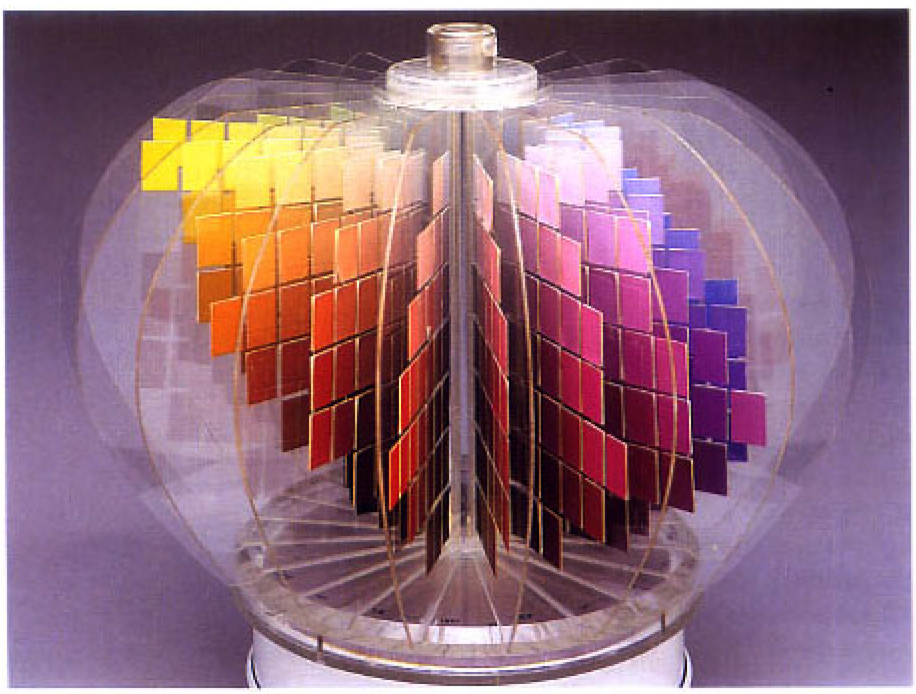
The resulting tertiaries will be as follows:

- yellow + green = yellow-green
- green + cyan = green-blue-green
- cyan + violet = blue-violet-blue (ultramarine blue)
- violet + magenta = violet-red-violet
- magenta + orange = red
- orange + yellow = yellow-orange.

Again, mixing the three primaries together in equal amounts gives us black.

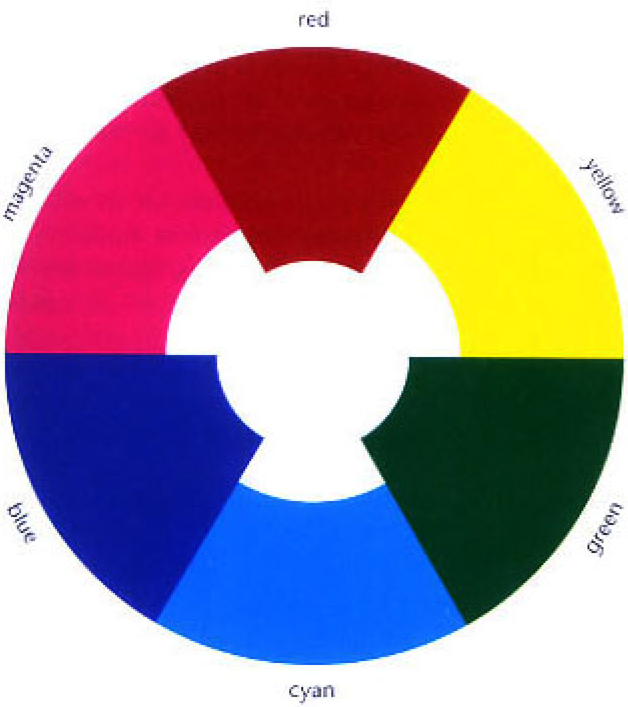
THE MUNSELL WHEEL

Albert Munsell (1858–1918) developed a partitive color system based on five primary hues or, as he termed them, **principal colors**: yellow, red, green, blue, and purple. These primaries are based on **afterimage** perceptions that derive from hues that we see in nature. Afterimaging is an optical reaction that occurs after we stare intensely at a hue and then shift our eyes to a white surface; this second hue is termed the afterimage. If, for example, we stare at a red dot, the resulting afterimage will be blue-green. Munsell set up each afterimage as the complement to his principal (primary) hues. A **complementary hue** is the hue that occupies the position directly opposite



2.5 The Munsell color tree. There are ten vanes to this tree, corresponding to the five primaries and five secondaries of the Munsell wheel (see fig. 2.4). In this view, the complementary primaries of yellow and blue-violet can be seen across from each other.

Light Wheel



2.6 The light wheel. This six-step additive color wheel consists of three primaries and three secondaries.

on a color wheel. From this base he was able to arrange his **Munsell wheel (fig. 2.4)**.

His arrangement resulted in the complementary combinations of yellow and purple-blue, red and blue-green, green and red-purple, blue and yellow-red, and purple and green-yellow. These afterimages comprise the secondary hues of the Munsell wheel. He further systematized the color wheel into a three-dimensional form that he termed a "tree" (**fig. 2.5**). Intervals of value, measuring the lightness and darkness of a hue, are shown along the trunk or vertical axis, with 0 as black and 10 as white. The intervals between are assigned the numbers 1 to 9. Any color along the innermost vertical axis is called a **neutral**, a nonchromatic hue of white, gray, or black which does not contain any pure hue. Branches or horizontal intervals measure the **saturation** or relative purity of each hue, with the pure hue being located at the outside edge. The remaining intervals along each horizontal branch consist of colored gray mixtures in varying degrees of purity.

We will explore Munsell's system further in the section on color theorists (see page 17). It is used by dye manufacturers for yarn and fabric coloration, as well as in interior design and in the production of cosmetics, computer hardware, and paint. For example, Liquitex acrylic paints carry Munsell color notations on their tube labels. Partitive color usage often relies on the interactions resulting from afterimaging. Because the Munsell wheel is the wheel based on afterimaging, we will base all our information concerning color on this wheel unless otherwise noted.

THE LIGHT WHEEL

The **light wheel** is based on the additive color system and provides information concerning light rays and transparent color. Here the primary colors that form the other hues are red, green, and blue. The secondaries are as follows:

- red + green = yellow
- green + blue = cyan
- blue + red = magenta.

Since these are combinations of colored light, when all the primaries are combined, white results. The total absence of light results in black. Because light is being added to light, the more color rays are mixed or fused with other color rays, the lighter they become. The light wheel is used for theatrical lighting and projection (**fig. 2.6**), and is now the basis for video and computer graphics as well.

THE VISUAL WHEEL

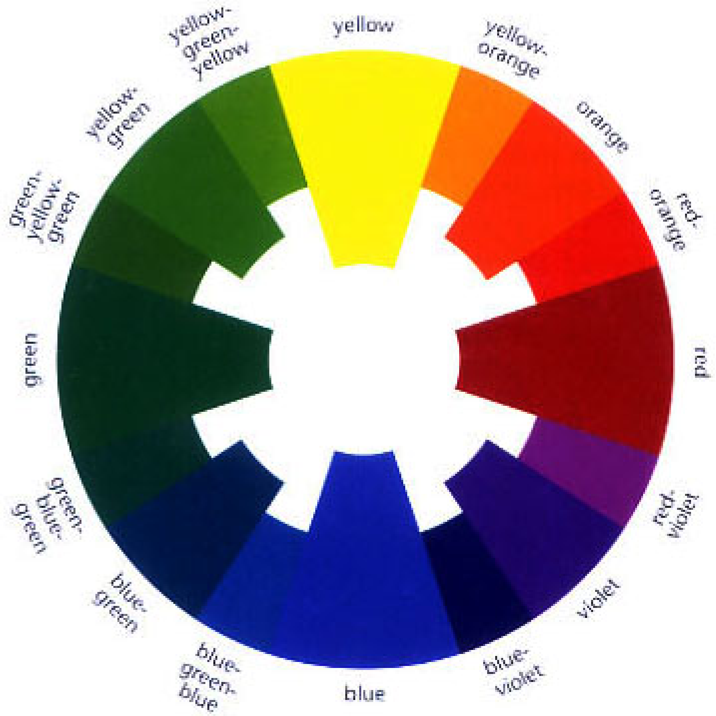
The **visual wheel** grew out of work done by Leonardo da Vinci (1452–1519) on complementary colors, and greatly influenced Renaissance painting. This wheel was the forerunner of the concept of partitive color theory and was used in a partitive as well as a subtractive manner. The visual wheel was then superseded by the Munsell wheel, which was more scientifically accurate.

The primary colors of the visual wheel are red, yellow, green, and blue (**fig. 2.7**). The secondaries are as follows:

- red + yellow = orange
- yellow + green = yellow-green
- green + blue = blue-green
- blue + red = violet.

The visual wheel is arranged so that the complementary combinations are yellow and blue, orange and blue-green, red and green, and violet and yellow-green. When these primaries are combined the result to the human eye is a gray.

Visual Wheel



2.7 The visual wheel. This sixteen-step partitive (and subtractive) color wheel consists of four primaries, four secondaries, and eight tertiaries.

CONCEPTS TO REMEMBER

- ☐ The three basic color systems are subtractive color, additive color, and partitive color.
- ☐ The five basic color wheels are:
  (1) the pigment wheel (subtractive color),
  (2) the process wheel (subtractive color),
  (3) the Munsell wheel (partitive color),
  (4) the light wheel (additive color), and
  (5) the visual wheel (subtractive and partitive color).
- ☐ Specific color wheel choice depends on the effects of color and imagery desired in the art medium employed. The painter uses both the subtractive and partitive wheels. The photographer uses the additive and partitive wheels.

Exercises

1. Make a list of various art media (painting, sculpture, printmaking, etc.), crafts (weaving, batik, ceramics, jewelry, etc.), and commercial visual media (interior design, architecture, advertising, photography, etc.). Note what color systems (subtractive, additive, partitive) and color wheels (pigment, process, Munsell, light, visual) would be used by each.
2. Create three compositions of identically-spaced stripes in an art medium of your choice. Within the first, choose a complementary pair of hues from the pigment wheel; within the second, a complementary pair from the Munsell wheel; and within the third, a complementary pair from the visual wheel.

CHAPTER 3

Color Theorists

In trying to understand the important influence of color on our lives, color theorists have from ancient times to the present attempted to explain both scientifically and psychologically how color reacts. In doing so they have devised systematic frameworks and rules for our dealings with color. Although color is a sensation, and as such its reactions cannot be neatly categorized, our awareness of the work of color theorists does help us in understanding color. Color usage is complex and knowledge of how color theory has evolved lets us utilize these various theories, where appropriate, in working with color.

COLOR THEORY IN THE ANCIENT WORLD

The first hint of **color theory** was formulated by the ancient Greek philosopher Empedocles (492–431 B.C.). Empedocles' observations of his surroundings led him to the conclusion that the eye of the observer perceived color; color is not a property of the object being observed. Democritus (?460–?370 B.C.) developed the first atomic theory. He stated that the world was composed of atoms and that color was the result of atomic arrangements. Here were the first bare bones of color theory evolving from a combination of speculation and observation. According to the great Greek teacher and philosopher Plato (428–347 B.C.), perception was a property of the individual perceiver—the problem, therefore, was how to distinguish between reality and appearance. Color is a sensation that allows us to describe what we see.

In *De Coloribus* (the first known color book), the Greek philosopher Aristotle (384–322 B.C.) attempted to explain the composition of colors and how they were related. Aristotle assumed that all colors were derived from the blending of sunlight, fire, light, and lack of light in varying degrees. Aristotle's hue identification included white, black, red, yellow, brown, violet, green, and blue, and he proposed that varying mixtures of black and white with these hues would result in the formation of all the perceived colors.

LEONARDO DA VINCI

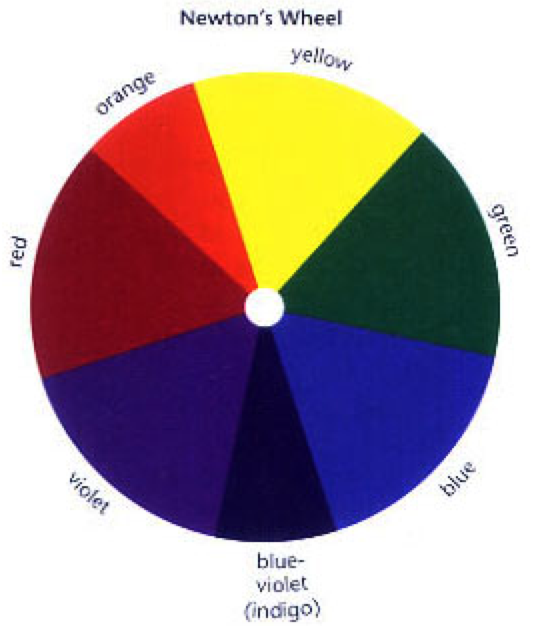
The Renaissance artist and scientist Leonardo (1452–1519) set out his beliefs on color theory in his *Treatise on Painting*, which was not published until 1651. He wrote that black and white were indeed colors, and assigned white, yellow, green, blue, red, and black as the simple or primary colors. This was the first appearance of the four primaries of the visual wheel, even though Leonardo did not arrange them in a circular configuration. Working by observation from his own optical reaction, Leonardo concluded that certain responses took place when colors were placed next to each other; this was later to become known as **simultaneous contrast**. Essentially he discovered that when placed side by side, complementary colors (or, as he termed them, direct contraries) intensify each other.

Leonardo was also extremely interested in developing what we now know as **atmospheric perspective**. This describes the tendency of forms seen at great distance to become uniform in hue and value. He recorded the sky changes and their effect on colors of objects both near at hand and in the distance, and wrote, "colors will appear what they are not, according to the ground which surrounds them."

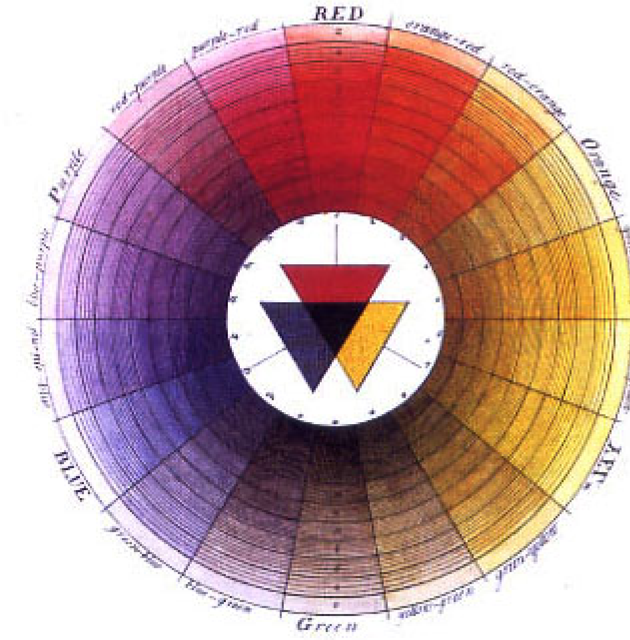
Leonardo ranked colors in importance, saying that white was the first and simplest of colors and represented light, second was yellow (earth), third was green (water), fourth was blue (air), fifth was red (fire), and sixth was black (total darkness). He also worked with modeling and shading of objects, using light and **shadow** effects (**chiaroscuro**, "light-dark" in Italian) in his painting, and further developed this concept into the technique known as **sfumato**, in which hues are softly graded and blended to give a hazy, blurred effect.

SIR ISAAC NEWTON

Isaac Newton (1642–1727) was interested purely in the physics of color, rather than in perception. He discovered that as a ray of white light passes and is bent, or refracted, through a prism it is broken into an array of colors, or spectral hues—red, orange, yellow, green, blue, indigo, and violet (see figs. 1.4, 1.5). He noted that white light was a mixture of all the spectral hues. He took this "array" and turned it into a two-dimensional circular model that became the first color wheel. Notice that the hue divisions of Newton's wheel are not equal but are based on the extension or proportion of each hue in relation to the spectrum (**fig. 3.1**). Newton found when mixing pigments of opposite hues on his wheel (complementaries) that "some faint anonymous colour" resulted. Newton was never able, in his



3.1 Newton's wheel. Newton proposed a color wheel based on the adjacent sequence of seven wavelengths within the visible spectrum (see fig. 1.5). The hue divisions are unequal because they are based on the proportion of each wavelength relative to others in the spectrum. The white at the center indicates the light source within which all the wavelengths are contained.



3.2 Harris's color wheel, from *The Natural System of Colors*, c. 1766. Royal Academy of Arts, London. Moses Harris derived his eighteen-step color wheel from the three primaries of red, yellow, and blue, which here overlap to black. As each hue approaches the center, it takes on deeper shades of gray.

experiments, to mix pigments of two or three of his hues to obtain white, because his theory was based on the mixing of light (additive color), while the mixing of hue pigments is based on subtractive color.

MOSES HARRIS

Moses Harris, an English entomologist and engraver (active 1766–1785), wrote *The Natural System of Colors* in 1766. In this book he presented red, yellow, and blue as the primary hues, which he termed "primitives." The mixture of these primitives produced the "compound" hues (secondaries) of orange, green, and purple. The primitive/compound mixtures were each categorized into two progressions—red and orange yielded red-orange which was more red than orange, and orange-red which was more orange than red. The Harris wheel was divided into eighteen equal hue divisions and each division was then graded by value, light (plus white) to dark (plus black) (**fig. 3.2**).

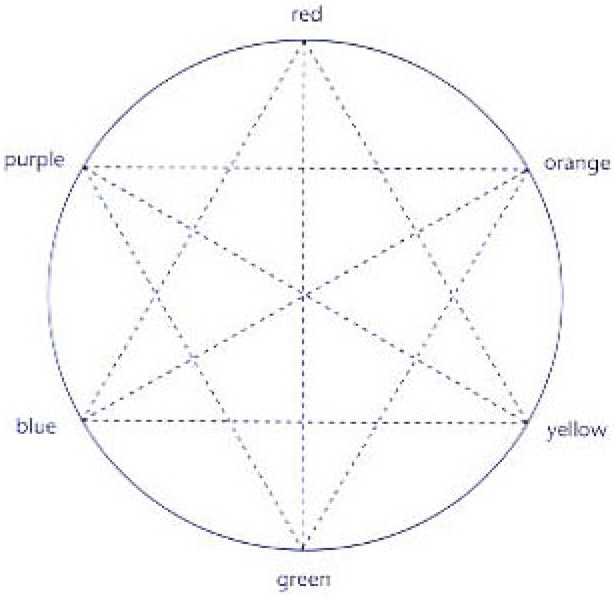
JOHANN WOLFGANG VON GOETHE

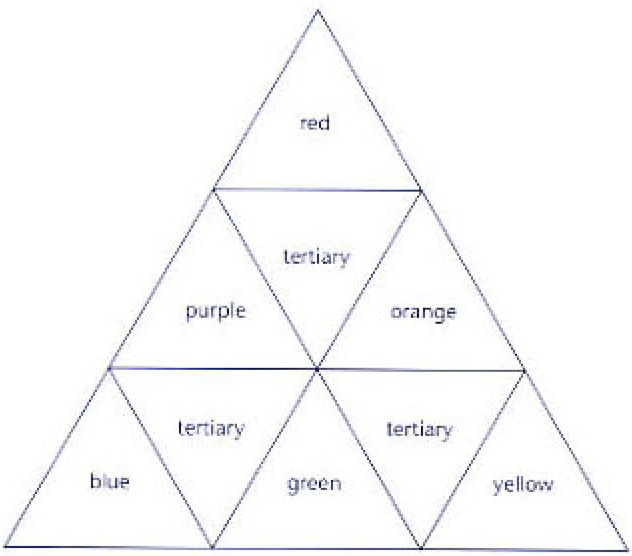
In 1810 the German poet Goethe (1749–1832) published his *Theory of Colors*, which he thought would be more important to posterity than his poetry. He was one of the first modern thinkers to investigate and record the function of the eye and its interpretation of color, rather than the properties of light. He was a vigorous opponent of Newton's physics of light.

The two-dimensional wheel he developed was based on a triad of primaries—red, yellow, and blue—with the secondaries as complements of the primaries. In addition to his color wheel (**fig. 3.3**), which reflected previous diagrams, Goethe formulated a color triangle which he felt further reinforced color relationships (**fig. 3.4**).

Goethe assigned a number to each of the hues according to their relative **luminosity** (the ability of the hue to give a glowing impression):

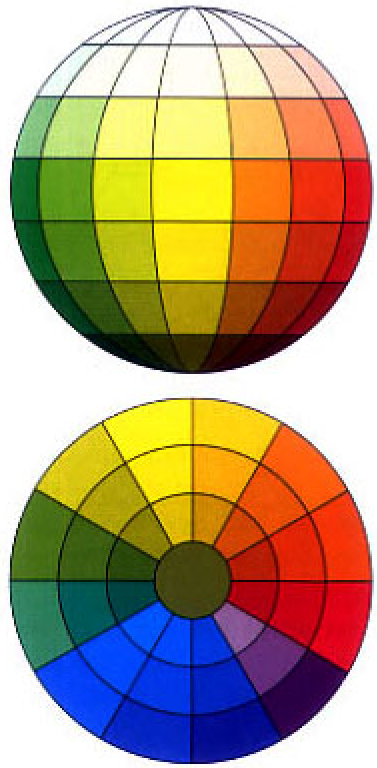
- yellow = 9
- orange = 8
- red = 6
- green = 6
- blue = 4
- violet = 3.





3.3 and 3.4 Goethe's color wheel (*above*) and color triangle (*below*). The corners of the triangle contain the primaries: red, yellow, and blue. The secondaries form the middle of the triangle's sides, connecting the primaries. The remaining areas are the tertiaries, which are the result of mixing two secondaries with the adjacent primary. These tertiary mixtures were less intense than what we commonly call tertiaries today.

White was the most luminous at 10 and black the least at 0. In fact, he explored every aspect of color and its reactions, including the role of complementary colors in creating shadows, simultaneous contrast, **successive contrast**, the effects of cast light on an object, and proportional color use, leaving us with one of the foremost research references available to artists in all fields of endeavor.



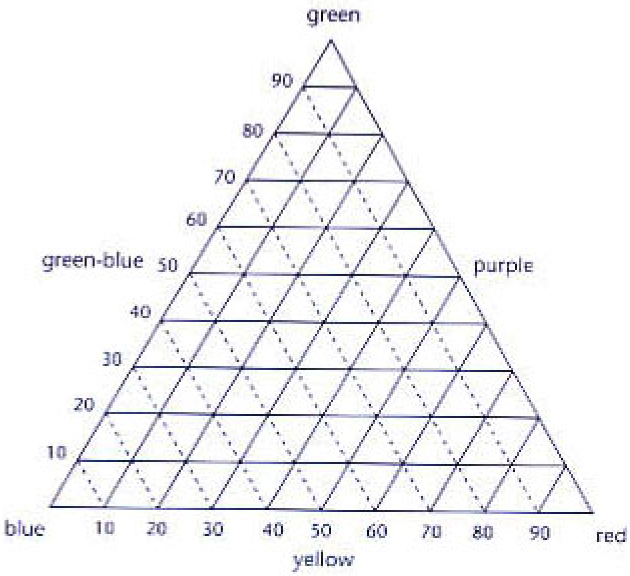
3.5 Runge's color sphere. The outer edges of Runge's sphere show near white at the top and black at the bottom (top diagram), with pure hues in the middle (equator). Note that the pure hues at the equator are different values, while the hues plus white at the top merge into the same value.

PHILIP OTTO RUNGE

Philip Runge (1777–1810) was a German painter. In his book *The Color Sphere*, published in 1810, he arranged twelve hues in a spherical format, thus giving us the first three-dimensional color model. Runge's primaries were still red, yellow, and blue, and the remaining nine hues were interspersed to form a diameter or equator around the center of the sphere (**fig. 3.5**). The hues were each mixed in two steps, with white on one side of this equator and two steps of black on the other side. In short, each of the hues evolved to black on one side of the sphere and to white on the other.

J.C. MAXWELL

Maxwell (1831–1879), a Scottish physicist, experimented with the concept of additive color and its resulting color combinations, as a property of the behavior of light. His two-dimensional color diagram took the form of a triangle with green, blue, and red at the points



3.6 Maxwell's color triangle. Maxwell's triangle was based on light mixtures that approach pure white at the center.

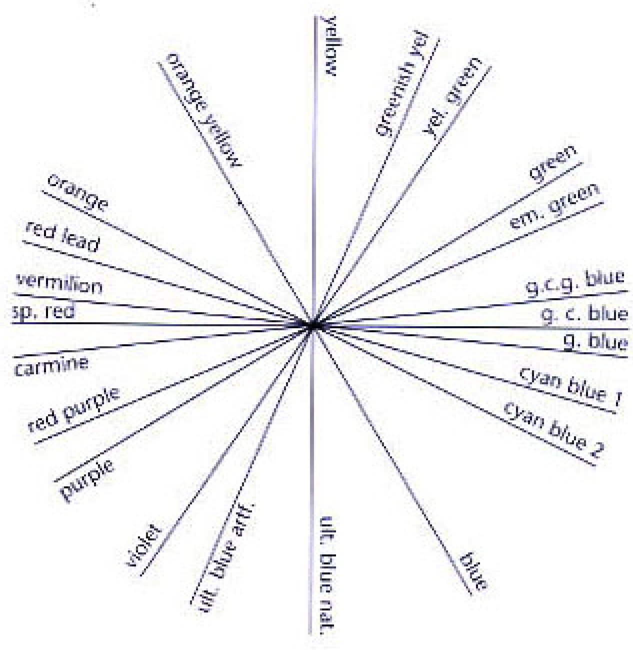
(primaries), and green-blue, yellow, and purple forming the sides, with white in the center (**fig. 3.6**). He also experimented with spinning colored discs (the Maxwell color discs) and discovered that when spun these color combinations formed other hues—red and green spun together, for example, resulted in a yellow reaction. Maxwell's work led him to the field of color photography, in which he proved to be a pioneer of modern-day photography.

MICHEL EUGÈNE CHEVREUL

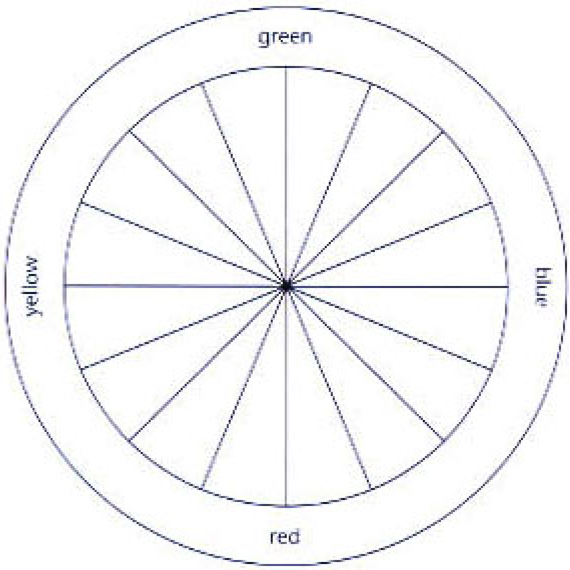
The French chemist Chevreul (1786–1889) was hired by the famous French tapestry-weaving studio Gobelins, to be its dye master. In this position he began his intensive investigation into color and its reactions. His findings became part of his major publication *The Principles of Harmony and Contrast of Colors*. He verified that all hues could be obtained from mixtures of the primaries red, yellow, and blue, but his greatest contribution was his recording of the reactions that colors have when placed side by side or in relationship to each other. This research led to the color theory laws of simultaneous contrast (based on complementaries), successive contrast (based on afterimages), and **optical mixing** (see pages 97–102). His research led to his proposing "color harmonies" which are used to this day in the form of **color schemes**. Although Chevreul was writing during the Impressionist period of art, his theories were more dramatically applied by Neo-Impressionists such as Seurat (see fig. 11.7).

OGDEN ROOD

The American Ogden Rood (1831–1902) received schooling in both art and science, and published his research from this dual point of view in 1879 as *Modern Chromatics*. He proposed that colors differed from one another as a result of three variables—purity (saturation), luminosity (value), and hue. His experiments were concerned with the optical mixing that occurs in **pointillism**, a painting technique in which dots of pure hues are placed together on a white ground so that they are mixed by the eye. While Rood's color wheel (a three-dimensional cone) was based on the primaries red, green, and blue, their arrangement was such that the complements were the result of afterimages, rather than the dull colors obtained by pigment mixing (**fig. 3.7**). Rood felt that once an artist knew what the direct complement or contrast of a hue was, he or she could imbue a glowing brilliance to a work that exceeded the hue's brilliance.



3.7 Rood's color wheel. In his book *Modern Chromatics* (1879) Rood emphasized the importance for artists of a sound knowledge of complements so that applied colors could then reveal their natural brilliance, even colors that are comparatively dull in isolation. In his own words, ". . . paintings, made up almost entirely of tints that by themselves seem modest and far from brilliant, often strike us as being rich and gorgeous in colour, while, on the other hand, the most gaudy colours can easily be arranged so as to produce a depressing effect on the beholder."[1]



3.8 Hering's primaries. Hering's primaries of red, yellow, green, and blue are the same as those on the visual wheel (see fig. 2.7).

EWALD HERING

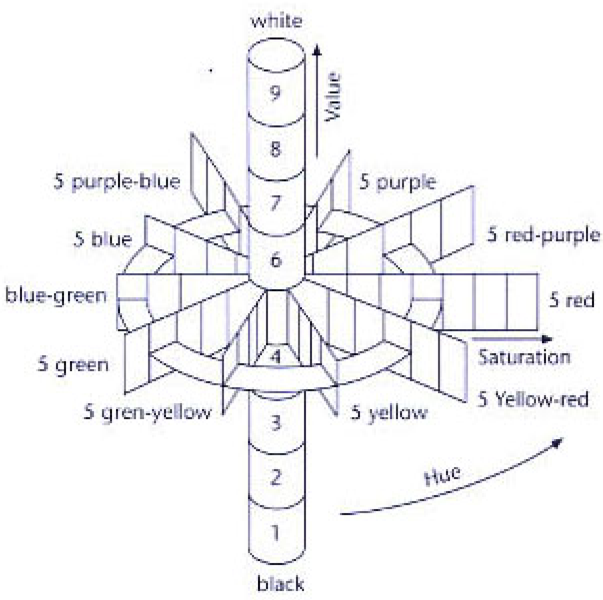
Ewald Hering (1834–1918) was a German physiologist and psychologist who was concerned with theories of color perception. He established his primaries as red, yellow, blue, and green (**fig. 3.8**); many color theorists today still refer to these four as the psychological primaries, or the primary colors of vision. The Hering color diagram was based on perception, not on the physical mixing of colors. It was triangular in form, with pure hue at one point, black at another point, and white at the third point. Both Wilhelm Ostwald's work (see page 18) and the Swedish Natural Color System (NCS) are based on Hering's theories.

ALBERT MUNSELL

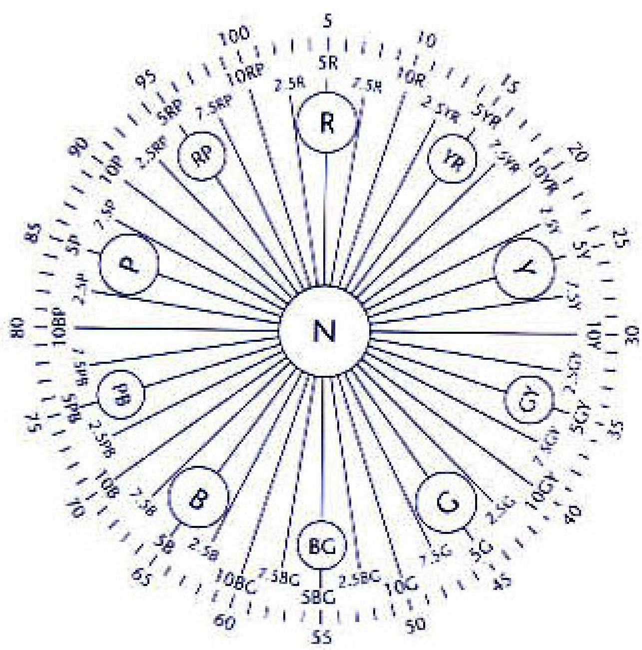
The life's work of American-born color theorist Albert Munsell (1858–1918) led to his system being adopted by the United States Bureau of Standards as the acceptable language of color. This language was published by Munsell as *Color Notation* in 1905. He followed Hermann Helmholtz (1821–1894) in stating that color could be described according to three variables—hue, value (lightness or darkness), and **chroma** (saturation or brightness). He assigned a numbering system to these variables as they occurred within each hue category. His experimentation led to his expansion of the primary hues (which he termed principal colors) to number five—red, yellow, blue, green, and purple. Afterimages of these principal colors formed the basis for Munsell's complementaries—red and blue-green, yellow and purple-blue, blue and yellow-red, green and red-purple, and purple and green-yellow.

As described in chapter 2 (pages 10–11), Munsell's color tree represents gradations of value along the vertical axis, and gradations in saturation or chroma as steps along the horizontal "branches." The "equator" of the solid shows the hues (**fig. 3.9** and see fig. 2.5). Munsell gave each of the hues the number 5 and an initial letter (or letters), so that red is 5R, yellow-red is 5YR. He allotted the hues that fall between the five principal and five complementary hues an intermediate numbering system, so that 10R is a hue that falls halfway between 5R and 5YR. The number 5, therefore, indicates the midpoint of each hue family (**fig. 3.10**).

Munsell expressed the value of the hue by adding a number between 0 and 9 as the second part of the notation, so that 5R5 is a middle-value red, and 5R9 is a very pale pink. Finally, Munsell added a notation after a slash to indicate the chroma, or level of saturation or purity, of the hue at that value, measured in equal steps from neutral gray to the greatest saturation seen in each hue at a particular value. So, a pure middle-value



3.9 A three-dimensional diagram of the Munsell tree. Hues are positioned on a vertical axis showing values from light (above) to dark (below). Saturation is measured on a horizontal axis, with dull-gray hues at the center evolving into the brightest hues at the outer extremities. This illustration shows saturation at the middle value of 5.



3.10 A cross-section of the Munsell tree. This bird's-eye view shows the five primaries and five secondaries of the Munsell wheel and tree (see figs. 2.4–2.5), with "N" signifying the neutral, non-chromatic value of hues closest to the vertical axis. The numbers 5, 7.5, 10, and 2.5 running clockwise around the two innermost rings of numbers signify different stages in the progression from one primary to the next secondary, and so on. Courtesy of GretagMacbeth, New Windsor, NY.

red is 5R5/14, whereas a less saturated red of equal value may be 5R5/6.

The Munsell notation may be summed up as follows: the first number and letter is the hue, the second number is the value, and the third is the chroma. Each plotting of a hue was flattened out into pages that became the branches of the Munsell color tree revolving around the value–scale trunk. This system allowed the artist to determine the components of a color without experimentation, and therefore to determine the reaction or interaction that a particular color choice would impart. It also provided pigment specifications that were precise, allowing industry to become color standardized.

WILHELM OSTWALD

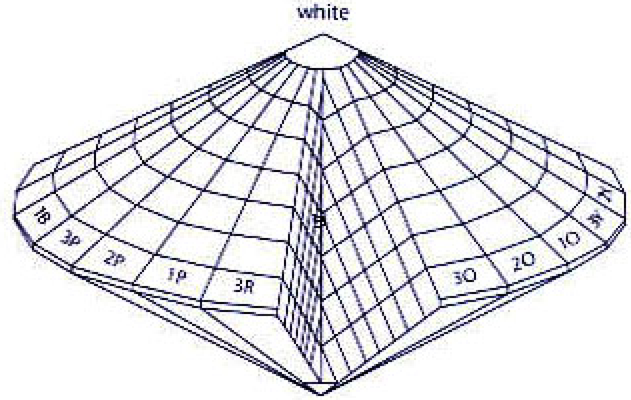
The Nobel Prize-winning German chemist Wilhelm Ostwald (1853–1932) based his color model on geometric progression. A value scale based on the absorption qualities (the quantity of white light absorbed) added arithmetically would result in a 1, 2, 3, 4 . . . format. However, when absorption is analyzed on a geometric basis, we see a scale of 1, 2, 4, 8, 16, 32 . . . This provided a scale with more optically equal steps in value gradation. Ostwald's resulting gray scale contained eight steps.

His color system consisted of two triangular solids joined at one side, with black at one point, white at the other, and twenty-four pure hues at the "equator" (**fig. 3.11**). He based his hues on the familiar red, yellow, and blue primaries. Ostwald's premise was that all colors are a combination of hue, black, and white. Thus the intermediate portions of his color triangles were based on percentages of black, white, and hue. Within each of these percentage mixtures the total was always 100 percent, which made them "complete." Ostwald termed the addition of white to a hue or color "tinting"; the addition of black, "shading."

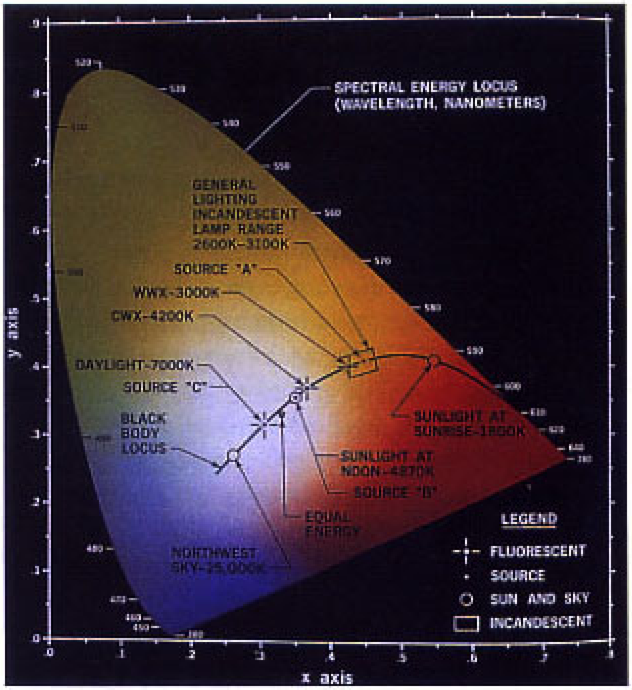
C.I.E.

At the 1931 International Commission on Illumination (Commission Internationale de l'Eclairage, or C.I.E.) the need for standardization of color notations was explored. The outcome was a precise color matching system based on lights. Here mechanics rather than observation or pigment measure served as the basis for color identification. A colorimeter was used to measure the three variables of any color: the luminance (intensity of light given off), the hue, and the saturation. Together, these three values determine the "chromaticity" of a color.

The C.I.E. chromaticity diagram, or triangle, has the hues (stated as spectral hues or wavelengths) around



3.11 Ostwald's color solid, from *Color Science*, 1931. Ostwald first presented his color specification model in 1917. It has since been criticized by some artists for being too scientific in the creation of artworks. Adding black and white to a hue to create gray is markedly different from Munsell's method of arriving at gray by mixing a hue with its complement.



3.12 The C.I.E. color diagram. The scientific foundation of the C.I.E. diagram affords a precise color standard for industry, but the diagram is not a practical tool for the artist.

the edge and the mixing or sum of these hues in the center, called E for equal energy (**fig. 3.12**). For light mixtures E is white; for pigment mixtures E is black or a dark neutral mixture. Although the diagram is termed a triangle, in fact it is a curve based on the luminosity curve.

The advantage of the C.I.E. system is that it provides industry with the means of accurately and consistently matching colors of barely perceptible differences. Such an objective standard eliminates differences in human interpretation, as well as problems caused by the fading of painted or colored swatches.

JOHANNES ITTEN

The Swiss teacher and artist Johannes Itten (1888–1967) is probably best known to the color student for his book *The Art of Color* and its condensed version *The Elements of Color*. Itten taught both color and design at the enormously influential Bauhaus School in Germany, where his approach to education included both mental and physical conditioning. Each morning Bauhaus students did aerobic-type exercises on the roof of the building prior to Itten's lectures and classroom work. Itten developed his color sphere and "star" for his Bauhaus preliminary course in 1919. The star was simply a flattened version of the sphere developed earlier by Runge (see page 15). However, Itten placed yellow at the top of the diagram because it was the brightest of the hues and the closest visually to white light. The diagram contained twelve hues that were each presented in seven gradations from light at the center to dark at the points (**fig. 3.13**). The advantage of this type of diagram was that the students could observe the differences in hues as well as the values of the hues simultaneously.

Itten encouraged students to explore color reactions and required from them many types of gradation scales, because he felt that gradations led to chromatic unity in any work. Students were encouraged to use rectilinear designs in a grid format for their experiments because color reactions could be easily observed. In his later work he proposed six basic contrasts of color:

1 light–dark
2 cold–warm
3 complementary
4 simultaneous contrast
5 quality or saturation
6 quantity or extension.

Itten's Wheel

3.13 Itten's color wheel. Itten employs the primaries red, yellow, and blue in the center triangle. This triangle is surrounded by the secondaries green, violet, and orange, which are the respective complements of the primaries. The outer circle is an arrangement of primary, secondary, and tertiary hues.

In 1961 Itten developed another wheel based on the primaries yellow, red, and blue which assumed a triangular position within the circle.

ALFRED HICKETHIER

The German painter Alfred Hickethier (1903–1967) concerned himself with color reproduction in printing, particularly the multicolor gravure process. His studies of pre-existing color theories led to his development and publication of standardized color sheets for printing. The *Hickethier Color System* was published in 1952, followed by *Color Mixing by Numbers* in 1963. Hickethier's premise was that the myriad of colors available to color printing, as well as other media, had to be easily obtained and identified. To this end he assigned his primary colors and black and white each a number: white 000 (the absence of all color), black 999 (the presence of all color), yellow (process yellow) 900, red 090 (his red is most visually identifiable as magenta), and blue 009 (his blue is most visually identifiable as cyan). Yellow occupied the first digit, magenta the second digit, and cyan the third digit of his three-digit system. These numbers represented the proportions or parts of a hue that were to be mixed with another to form other colors. Thus orange was numbered 990 or 9 parts yellow, 9 parts magenta, and 0 parts cyan, leading to an equal mixture of yellow and magenta. This numbering system allowed for observation of pale colors and color mixtures not accounted for in other systems. Hickethier used a color solid in the form of a cube for his system. This solid, which contained one thousand colors, had the primaries yellow, red (magenta), and blue (cyan) on the outer edges with ten intervals or steps between (0 = no color to 9 = full intensity). His system allows for very precise mixing of color that results in the same color each time an identical combination is mixed.

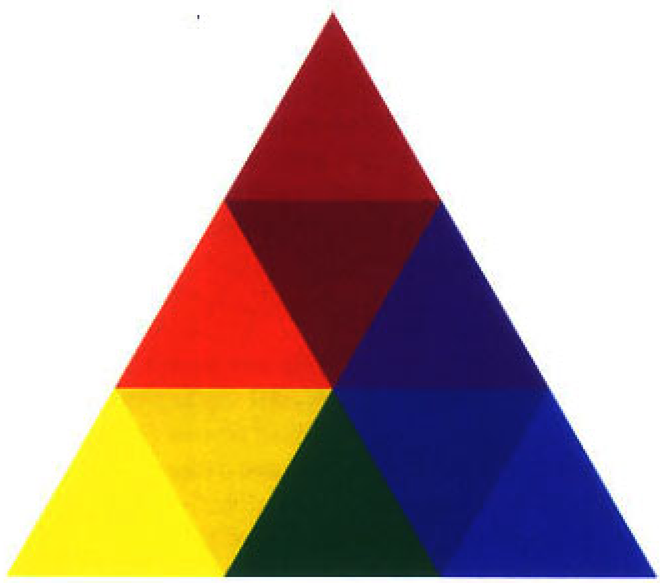
JOSEF ALBERS

As a teacher at the Bauhaus School, Josef Albers (1888–1976) became absorbed with how color reacts and interacts. He not only investigated color interactions on his own by developing exercises but insisted that students pursue independent investigations. While at the Bauhaus, he refined Itten's work (see page 19) as well as that of the abstract painter Wassily Kandinsky. The teaching diagram he used most often was a triangle, very much like Goethe's color triangle, which had red, yellow, and blue at its points, orange, violet, and green at the midpoints, with red-gray, yellow-gray, and blue-gray in between (**fig. 3.14**).

After Bauhaus, Albers came to the United States, where he eventually became a member of the fine arts faculty at Yale. Here he deepened his explorations into color theory and produced the book *Interaction of Color* (1963). Much of the content of his course was based on the phenomenon of simultaneous contrast. He was not just interested in the optical mixing that results from a pointillistic style, as shown in Seurat's painting technique (see fig. 11.7), but he also became absorbed in the reactions that occur where edges of color meet (see page 101). In his own paintings, and in those of his students, Albers used few colors and strong contrasts in a rectilinear format. These formats were used over and over again to investigate the infinite color combination possibilities and their varying effects. This type of thinking led to his "Clef" series and his famous "Homage to the Square" series. Albers did not confine his investigations of color to painting and printmaking alone, but explored how varied materials interacted. This is most evident in the weavings executed by his wife, Anni.

FABER BIRREN

At his death, Chicago-born and educated Faber Birren (1900–1988) was completing yet another book on color to add to his extensive list of more than twenty-four books and several hundred published articles on



3.14 Albers's color triangle. While at the Bauhaus, Albers used this color diagram (developed with Hirschfield-Mack) in his classes.

the subject. His color education began at the University of Chicago's School of Education under Walter Sargent. Birren went on to become one of the best-known and most widely read color authorities and consultants of the twentieth century.

In 1934 Birren designed his "Rational Color Circle," which arranged hues in equal intervals but tended to include more warm than cool hues in its make-up, so that the neutral gray "center" was asymmetrically placed. His rationale for this was that the eye sees more warm hues than cool ones. Although he retained the premise that red, yellow, and blue were primaries, within the warm area of his wheel he added a leaf green and within the cool area a turquoise. Red and green were complementary, and could function as either warm or cool.

Like Itten, Birren was interested in color harmonies. Basing his work on that of Chevreul, he proposed a "harmony of colors" as follows:

1 elements of harmony
2 harmony of adjacents
3 harmony of opposites
4 harmony of split-complements
5 harmony of triads
6 harmony of dominant tint.

In 1937 he developed a color triangle as part of his continuing investigation of the "harmony of color forms". This triangle dealt with the visual and psychological aspects of any color. He stated that there are pure colors or hues, white, and black. These three elements at the points of the triangle can be combined so that white added to a color gives a tint, black added to a color gives a shade, and black added to white gives a gray. They were placed intermittently on the triangle. The center of the diagram showed tone that is a combination of the three elements of black, white, and color.

Using his "harmony of color forms," which Birren felt charted color effects, unlike the color schemes used until this time, he evolved what he termed the "new perception" of color. Among these color effects we find the following:

1 the effect of luster
2 the effect of iridescence
3 the effect of luminosity
4 the effect of transparency
5 the effects of chromatic light
(see pages 111–114).

FRANS GERRITSEN

Dutch color theorist and artist Frans Gerritsen first published his color theories in 1975 as *Theory and Practice of Color*, to be followed in 1982 by his *Evolution in Color.* Gerritsen based his work on the laws of perception. He felt that previous color theories had been based on subtractive theory, additive theory, or partitive theory, which did not share a common point of view—additive worked with colored light, subtractive worked with actual pigment mixing, and partitive worked with reactions of color when placed side by side. All the theories did, however, have one significant thing in common—the eye and its reactions to color combinations.

Gerritsen came to the conclusion that the human eye has specific color sensitivities—if the entire visible spectrum were viewed in terms of a narrow band of color at a time, the eye would show that it was most sensitive to blue, green, and red. These colors became his new primaries. All other colors, he felt, could be created by combining these three primaries. For example, the color yellow is situated on the spectrum midway between red and green, therefore the sensation of yellow is created by the "spilled-over" energy sources from the red and green. Gerritsen believed that all current color theories could be explained in terms of his own concept if they were viewed from the perspective of the eye or, more simply, the light that is entering the eye. He established yellow, magenta, cyan, and black as the new primaries for photolithography.

Gerritsen's color wheel identified colors by a numbered position on a multi-dimensional complex shape where the primaries were designated by absolute wavelengths and intensities between 0 and 100. This system, he claimed, could positively identify over six million different colors. In summary, Gerritsen accomplished the following:

1 He established that the eye was the point at which all color theory started.

2 He fixed the colors of red, green, and blue (light sources) as the primaries for all future color theory work.

3 He eliminated the confusion between the different color theories by re-interpreting them in terms of his new concept.

4 He put all future color research on a sound scientific basis.