Sources of Color

8

Color surrounds us. It is a sensation that adds excitement and emotion to our lives. Everything from the clothes we wear to the pictures we paint revolves around color. In this chapter, methods of producing and manipulating color through the use of paints, dyes, filters, and lighting will be explored.

8.1 Spectral Color

In the 1660s, English physicist and mathematician Isaac Newton performed a series of experiments with sunlight and prisms. He allowed a narrow beam of sunlight formed by a hole in a window shade to pass through a triangular glass prism. Newton found that the prism produced an elongated patch of multicolored light on the opposite wall as shown in Fig. 8.1. While this phenomenon had been known at least since the time of the Egyptians, Newton was the first person to provide a satisfactory explanation of the production of the spectral colors. This phenomenon is known as *dispersion* of light.

Proof that the spectral colors are not added by the glass prism but actually exist in the white light came from an experiment in which Newton added a narrow slit that allowed only a single spectral color to fall on a second prism, as shown in Fig. 8.2. Spectrally pure red light falling on the second prism, for example, remained red after it passed through the second prism. Newton described such light from a narrow portion of the spectrum as "homogeneal"; today we call it *monochromatic* (meaning "one color").

The modern *spectroscope* is an instrument that measures the power (in watts) of the components of light at various wavelengths. Light entering the spectroscope is spread into a spectrum by a prism (or a diffraction grating; see Sect. 5.9). A detector

T. D. Rossing and C. J. Chiaverina, *Light Science*,
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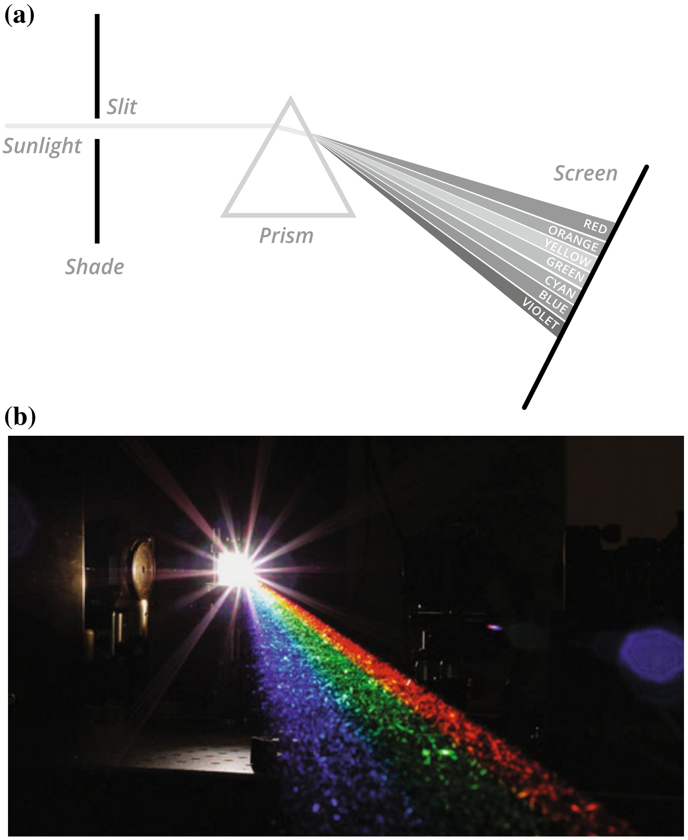


Fig. 8.1 **a** Diagram of Newton's famous prism experiment. **b** A recreation of Newton's experiment using a prism and an incandescent source in place of the Sun (Peeter Piksarv (https://commons.wikimedia.org/wiki/File:Valge_valguse_spekter.jpg), "Valge valguse spekter", https://creativecommons.org/licenses/by-sa/3.0/legalcode)

moves across the screen to measure the power at each wavelength, known as the *spectral power distribution* or SPD. Figure 8.3 shows SPDs for the blue, green, and red portions of the spectrum. The response of our visual system to a particular SPD can generally be predicted using our knowledge of the human visual system. However, it is more difficult to deduce the SPD of light from the visual response it produces, as we shall see, because a given response can often be produced by different SPDs.

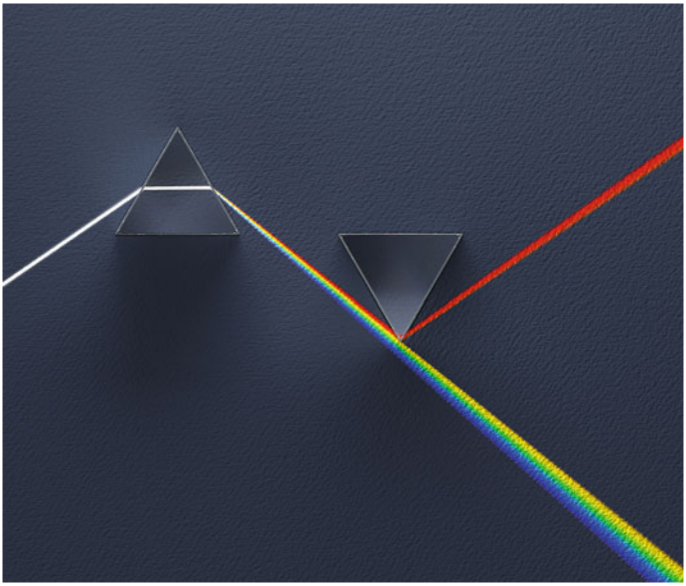
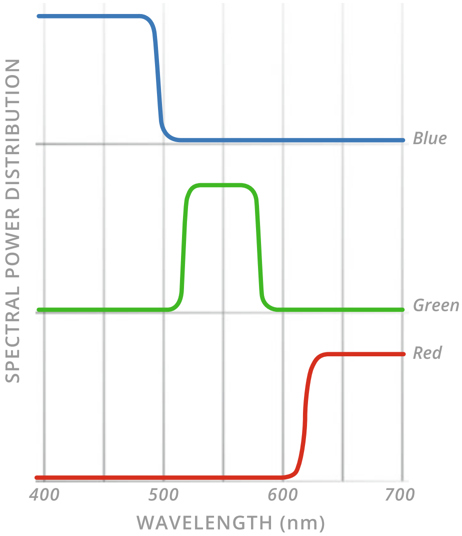


Fig. 8.2 Newton's experiment with two prisms showing that spectral colors (red in this example) cannot be further subdivided into other colors (David Parker/Science Source)

Fig. 8.3 Spectral power distribution (SPD) for the blue, green, and red portions of the spectrum



8.2 Additive Color Mixing

It is possible to mix red, green, and blue light in the right proportions to obtain nearly any desired color. We can even obtain white light. While it is possible to use other combinations of three colors, the range of colors obtainable by additive mixing may then be smaller. To be more specific, the “best” red, green, and blue lights to use have wavelengths of 650, 530, and 460 nm, respectively. The phosphors used in color television (which works by additive mixing) are the additive primaries, as saturated as phosphors will allow.

Additive color mixing is easily accomplished by projecting nearly monochromatic lights from two or more projectors onto a white screen. When a beam of red light is projected so that it overlaps a beam of green light, the result is yellow; red and blue lights produce magenta; blue and green lights produce cyan. An additive mixture of red, green, and blue (with proper luminant intensity) produces white, as shown in Fig. 8.4. The complementary pairs in additive mixing are red/cyan, green/magenta, and blue/yellow.

Three beams of light having wavelengths around 650 nm (red), 530 nm (green), and 460 nm (blue) can be used to obtain almost any desired color by additive mixing. You are encouraged to do this experiment yourself, if you have not already done so, by using color filters with slide projectors, colored LEDs, or a commercial light box (see Experiment 8.1 in Appendix J).

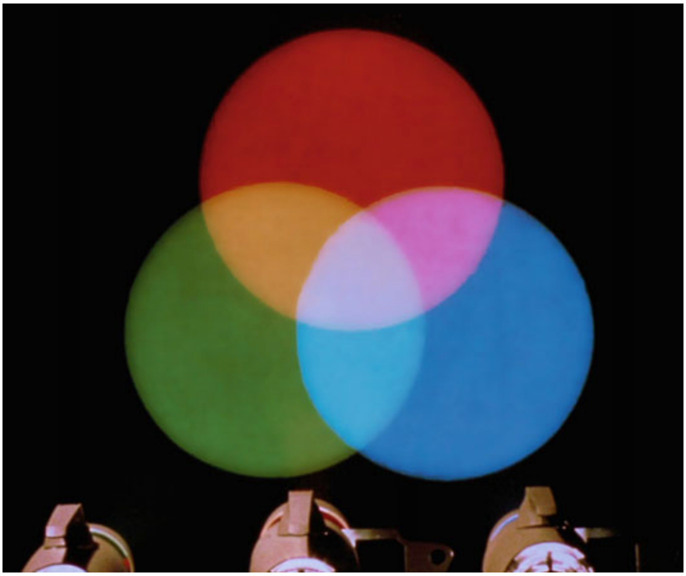


Fig. 8.4 Additive color mixing by overlap of red, green, and blue light (Courtesy of Kodansha, Ltd.)

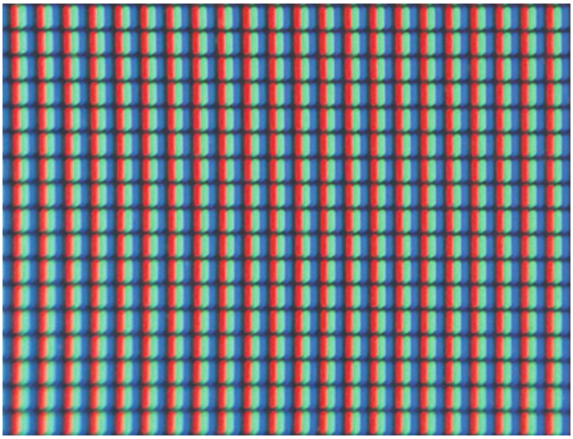


Fig. 8.5 A magnified image of a computer screen revealing colored pixels. The eye additively mixes the small picture elements to produce virtually any color

Three colors that can produce white light (or light of any color) are called *primary* colors. They need not be monochromatic, although they often are. There is no unique set of primaries, although some choices will provide a wider range of colors than others. The most widely used primaries for additive color mixing are red, green, and blue.

Fig. 8.6 The Crown Fountain, by contemporary Spanish artist Jaume Plensa, in Chicago's Millennium Park uses partitive mixing to form colored images (Serge Melki from Indianapolis, USA (https://commons.wikimedia.org/wiki/File:Chicago_-_Crown_Fountain_-_Millennium_Park_(2713868085).jpg), "Chicago—Crown Fountain—Millennium Park (2713868085)", https://creativecommons.org/licenses/by/2.0/legalcode)

Any two colors that produce white light when added together are called *complementary*. The complement of a primary color is called a *secondary* color. Thus, cyan (blue + green) is the complement of red, magenta (blue + red) is the complement of green, and yellow (green + red) is the complement of blue. Note that yellow and cyan can also be spectral or monochromatic colors, thus illustrating the fact that the same visual response can result from different SPDs.

Additively mixing colors can also be achieved by placing separate sources so close to each other that the eye cannot see them as separate (how close is this was discussed in Chap. 5). This type of additive mixing, sometimes called *partitive mixing*, is used in television screens and computer monitors (see Fig. 8.5).

Partitive mixing is also widely used in large-scale electronic displays that are often found at sporting events, concerts, in transportation hubs, and in artistic installations. The Crown Fountain in Chicago, shown in Fig. 8.6, employs partitive mixing through the use of closely spaced LEDs.

As was discussed in Chap. 5, partitive mixing was also used by the Pointillist painters, who put small dabs of different colored paints near each other (see Fig. 5.23). When the painting is viewed close up, the individual dots can be seen; but at normal viewing distance, the colors fuse to give an additive color. Textiles

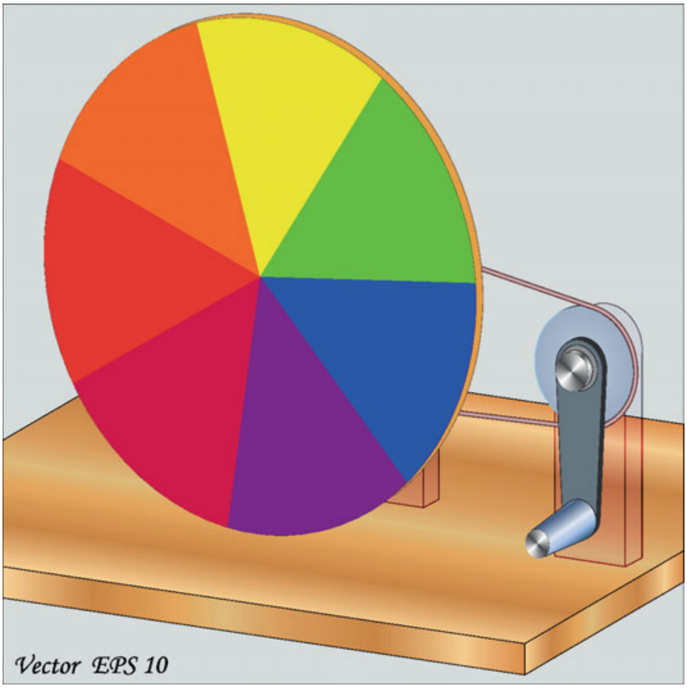


Fig. 8.7 Different hues may be produced by adjusting colored sectors on a color wheel (Fouad A. Saad/Shutterstock)

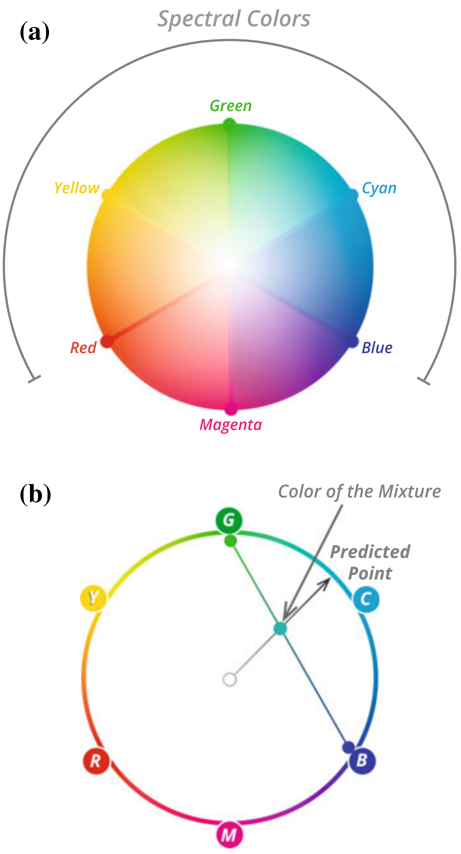


Fig. 8.8 **a** Newton's color circle shows the range of spectral colors. **b** The result of adding two colors (blue and green here) is represented by a point on the line joining the two colors; its hue is indicated by where a line from the center through the point meets the circle

often achieve their colors by partitive mixing, using a tight weave of two different colors in the warp and weft.

Another way of mixing colors additively is to display them in rapid succession so that the afterimage of one mixes with the image of the next. A simple device using this effect is the rotating color wheel, shown in Fig. 8.7. By adjusting the size of the colored sectors, different hues can be obtained, including a neutral gray (the luminance is generally insufficient to make the gray appear white).

The additive relationships between colors can be illustrated using *Newton's color circle*, shown in Fig. 8.8. The three primary colors are arranged around a circle with the complementary secondary colors placed directly opposite them. Thus, the colors red through blue are in the same relative positions as they fall in the spectrum (violet at the extreme end of the spectrum is included with blue). Note that magenta (or "purple") is not a spectral color. Magenta cannot be produced by monochromatic light; it can be seen only when the spectral power distribution contains both short and long wavelengths (by combining red and blue light or by subtracting green from white light). Newton closed the color circle with magenta because it logically fits there, opposite to its complement, green, not because this position represents a physical aspect of light.

This arrangement allows us to predict the result when two colors are added together. We need to draw only a line connecting two colors, as shown in Fig. 8.8b. The resulting color lies somewhere on that line, depending upon the relative brightness of the two colors, and the hue of this color is represented by a position on the circumference located by drawing a second line from the center of the circle outward through this point. When blue and green lights of nearly equal brightness are combined, the resulting color comes close to cyan, as shown in Fig. 8.8b.

8.3 Transmission and Reflection of Colored Light: Subtractive Color Mixing

Subtractive color mixing occurs when light passes through two or more selectively absorbing materials, such as two color filters. Dyes or pigments can be mixed together to form a single color agent that will absorb selectively. The process is called subtractive because each filter or pigment absorbs certain portions of the spectrum, leaving the light with a hue complementary to that subtracted. A piece of glass that absorbs the blue and green wavelengths of white light appears red because it transmits only the longer wavelengths.

The appearance of a colored filter may give little indication of its spectral absorption curve. Two filters that appear to have the same color may transmit light of different colors when combined with another colored filter. To predict the result of combining two filters (or mixing two pigments), the transmittance curves must be known. Transmittance curves tend to have rather complicated shapes; to better understand color mixing, we consider ideal filters that transmit 100% at some wavelengths and totally absorb all others. Transmittance curves of ideal blue, green, and red filters are shown in Fig. 8.9a–c.

For subtractive mixing, it is instructive to consider filters that pass the complements of the additive primaries. For example, yellow is the complement of blue, so it can be made by absorbing the blue in white light. Similarly, magenta results from absorbing the green in white light, and cyan results from absorbing the red. Thus, yellow, magenta, and cyan may be considered the three *subtractive primaries*, and their idealized transmittance curves are shown in Fig. 8.9d–f. Combining the three filters (d–f) will absorb all colors and produce black; similarly, combining any *two* of the filters (a–c) will produce black. Combining two of the filters (d–f), however, will give one of the additive primaries. For example, passing white light through the magenta filter (f) will subtract the green primary, leaving red and blue, as shown in Fig. 8.9g; a cyan filter will remove the red, leaving blue.

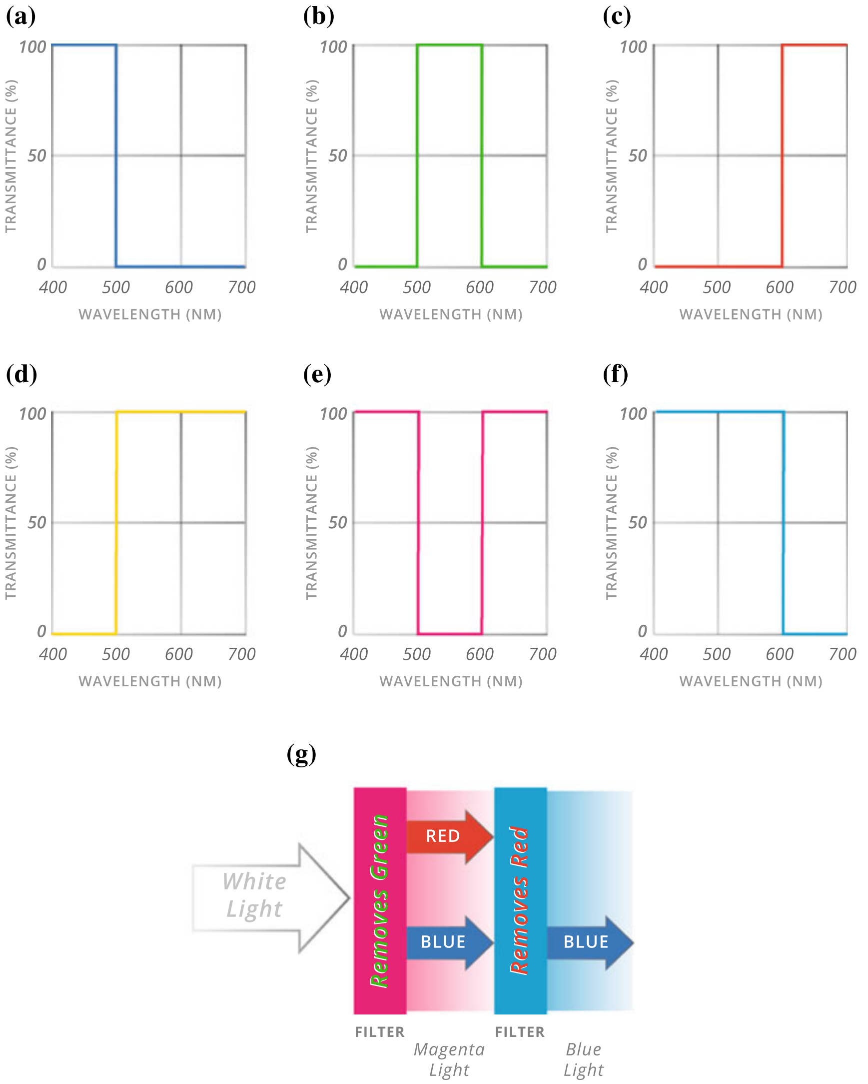


Fig. 8.9 Transmittance curves of ideal filters: **a** blue, **b** green, **c** red, **d** yellow, **e** magenta, **f** cyan; **g** illustrates passage of white light through a magenta filter (which removes green) and then a cyan filter (which removes red)

Simple subtractive mixing is illustrated in Fig. 8.10. The figure shows the effect on white light of three partially overlapping broadband filters that produce subtractive mixing. A subtractive mixture of cyan and magenta gives blue; a subtractive mixture of cyan and yellow gives green; a subtractive mixture of yellow and magenta gives red; a subtractive mixture of yellow, cyan, and magenta gives black.

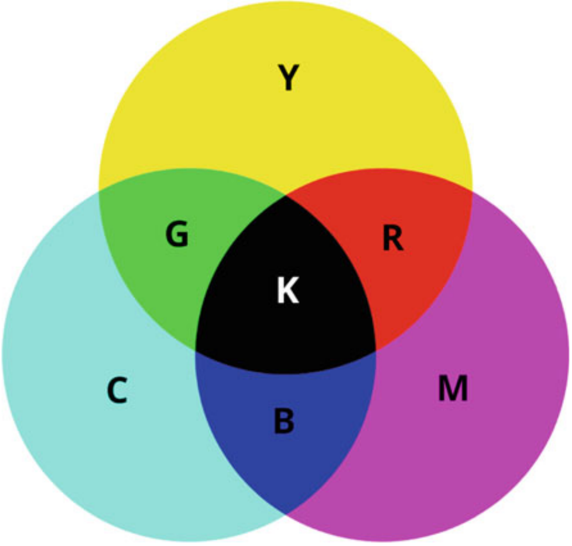


Fig. 8.10 Simple subtractive mixing. R = red; G = green; B = blue; C = cyan; M = magenta; K = black

Primary colors are simply hues you start with to mix others. Designating certain hues as primaries is an arbitrary convention that depends on who makes the selection. Red, yellow, and blue are generally considered the artist's primaries; by mixing appropriate amounts of these pigments, almost any other hue can be produced. We have seen, however, that yellow, magenta, and cyan (the complementaries of blue, green, and red) also work well as subtractive primaries.

Manufacturers of light filters often provide a spectral transmittance curve for each filter that indicates the percentage of light that is transmitted at each wavelength (called simply the *transmittance*). Figure 8.9 shows the transmittance curves for "ideal" filters. At each wavelength the transmittance is either 0 or 100%. In real life, no such ideal filters exist; more realistic transmittance curves for stage light filters are shown in Fig. 8.11.

Spectral and Monochromatic Filters

It is common practice to label a filter by the hue it produces from a beam of white light. This is useful but is imprecise and sometimes misleading. On the other hand, the transmittance curve of a filter completely describes its effect. Transmittance curves for three different types of yellow filter are shown in Fig. 8.12. The common non-spectral filter used in colored stage lights, for example, transmits a rather broad range of wavelengths from green through red. Yellow light can also be obtained from a *spectral* filter that transmits a rather narrow range of wavelength or by a *monochromatic* filter with an extremely narrow range of wavelength.

The colors from the nonspectral, spectral, and monochromatic filters in Fig. 8.12 may produce light with the same hue (yellow), but they will differ in saturation. The spectral filter produces greater saturation than the non-spectral one but at the expense of brightness. Spectral and monochromatic filters are not commonly used on the stage because they pass such a narrow portion of the spectrum.

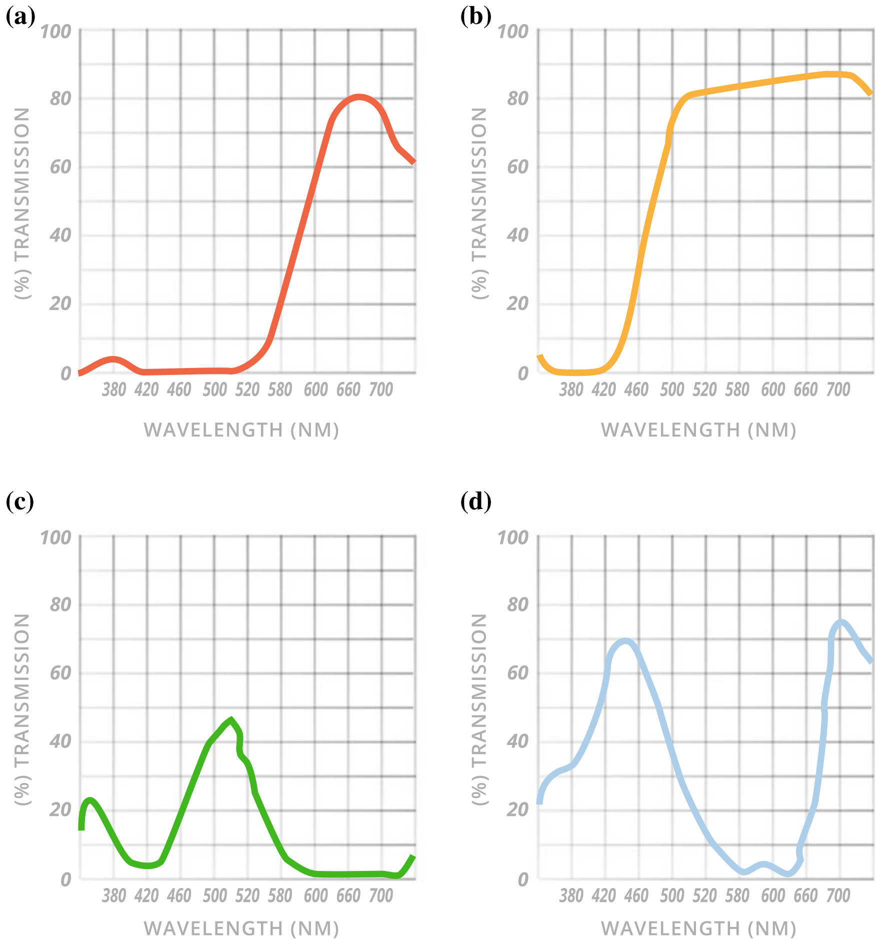


Fig. 8.11 Transmittance curves for stage light filters: **a** light red; **b** medium yellow; **c** Kelly green; **d** sky blue (Courtesy of Roscoe Laboratories)

A filter that has the same transmittance for all wavelengths is called a *neutral density filter*. Neutral density filters are useful in photography. A 50% neutral density filter transmits 50% of the original beam power at each wavelength and 50% of the overall light intensity.

Spectral Power Distribution of Filtered Light

In Chap. 7 we discussed the spectral power distribution of light from different light sources, including blackbodies, incandescent lamps, fluorescent lamps, and gas-discharge tubes. If we wish to know how light from one of these sources will appear after it passes through a filter, we can combine the spectral power distribution (SPD) of the light source with the transmittance curve of the filter, as shown in Fig. 8.13. The SPD of the emerging light will exhibit features that are characteristic of both the light source and the filter.

Fig. 8.12 Transmittance curves for three different types of yellow filter

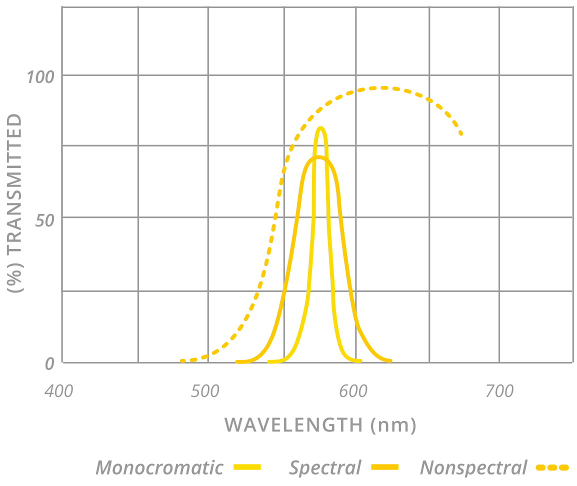
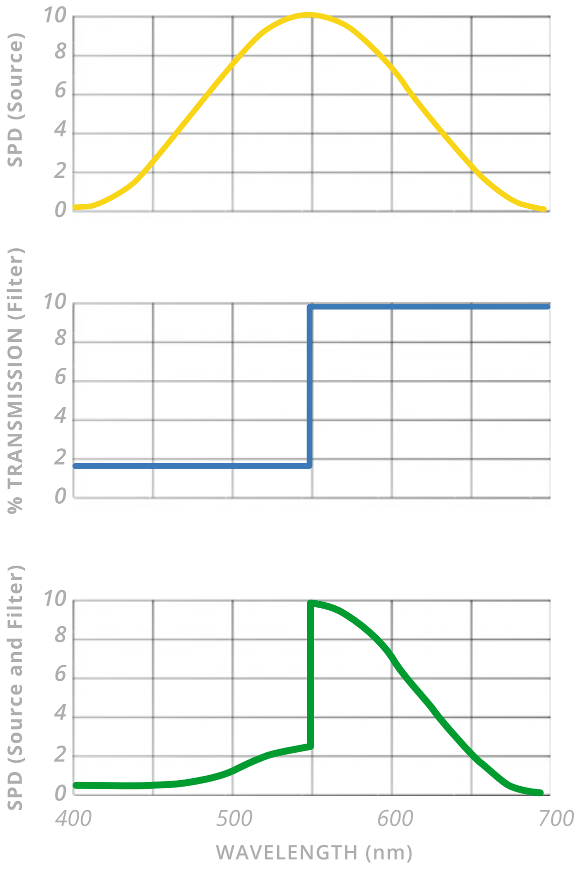


Fig. 8.13 The SPD of light emerging from a filter combines the SPD of the light source with the transmittance of the filter (After Williamson and Cummins 1983)



Spectral Reflectance

The way in which a surface affects the SPD when reflecting light is described by its *spectral reflectance curve*. This gives the percentage of light reflected at each wavelength and it determines the color an object appears to have when viewed in white light. Spectral reflectance curves of three common food products are shown in Fig. 8.14. Note that butter reflects a higher percentage in the red portion of the spectrum than a ripe tomato. It has a yellow hue, however, because it also reflects in the green portion of the spectrum, while a tomato does not.

The SPD of light reflected from an object will be determined by the SPD of the incident light combined with the spectral reflectance curve, much in the manner of transmitted light, as illustrated in Fig. 8.13. Careful attention must be applied to selecting the light source to be used to display paintings of various types in a museum, for example. In fashion magazines, much attention is given to the effect of illumination on the color of lipstick, eye shadow, and dress color.

Figure 3.11 illustrates the difference between regular or *specular* reflection and *diffuse* reflection. A surface that provides mostly specular reflection is called a *glossy surface*, whereas one that provides mostly diffuse reflection is called *matte*. Reflection from most surfaces is partly specular and partly diffuse. The interplay between the two can be quite fascinating because the proportions change with the direction of illumination and viewing angle. Artists often make use of this in painting, including areas suggesting specular reflection to emphasize form and enhance depth.

The Spanish painter El Greco sometimes used generous areas of white to highlight robes and faces in portraits. This can be seen in his *The Burial of the Count of Orgaz* (Fig. 8.15). Several areas of this painting seem to shimmer. As art historian Jonathan Brown observes, “Each figure seems to carry its own light within or reflects the light that emanates from an unseen source.”

The nature of the reflecting surface distinguishes “flat” paint from “glossy” paint. Glossy paints produce specular reflection, in one direction at least, and the colors that reflect from a glossy surface are generally more saturated than those

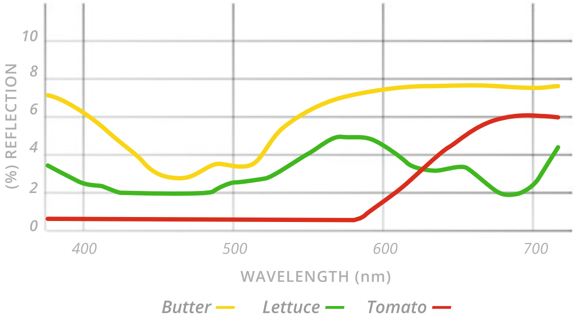


Fig. 8.14 Spectral reflectance curves for butter, lettuce, and tomato (After GE publication TP-119)

Fig. 8.15 El Greco's *The Burial of the Count of Orgaz* demonstrates the interplay between diffuse and specular reflection. Careful inspection reveals an image produced by specular reflection from the Count's armor (El Greco [Public domain], via Wikimedia Commons)

reflected from matte surfaces. Artists realize that the texture of a surface can be suggested by the degree of saturation of its color. Photographers know that moistening a surface with water darkens the area and provides more saturated colors. A similar effect is seen when wood is varnished to enhance the colors of the grain texture.

8.4 Pigments and Dyes

Paint pigments and dyes are the traditional sources of color available to the artist. A pigment is a finely divided, colored substance that imparts its color effect to another material either when mixed with it or when applied over its surface in a thin layer. Paint pigments, such as shown in Fig. 8.16, are usually powders that can be suspended in a medium such as oil or acrylic to form the paint. Pigments may be derived from a variety of natural sources including vegetables, animals, and minerals. They may also be synthesized.

Colored substances that dissolve in liquids and impart their color to materials by staining are classified as dyes. When dissolved in a solvent, the individual molecules of the dye become separated within the solvent. These individual molecules absorb colors selectively. Plastic filters for stage lighting and photography consist of dyes dissolved in clear plastic or gelatin. Dyes dissolved in water or other solvents are used in color fabric and paper.

Between soluble dyes and insoluble paint pigments is another category of coloring agents known as *lakes*, which are pigments prepared from dyes. They are essentially particles of translucent colorless alumina (aluminum oxide) whose color is determined by the dyes applied to them. In fabric dyeing, lakes are useful when the dye itself will not adhere to the fabric. The alumina particles suspended in water adhere to the fabric and react with the dye to form a fast color. Lakes have been used for centuries to enrich coloration in paintings.

Pigments used by painters illustrate the principles of subtractive color mixing. In oil painting, for example, the pigment is generally suspended in a binder, such as linseed oil, which dries to provide a protective cover. Light shining on the binder

Fig. 8.16 Pigments appear colored because they selectively reflect certain wavelengths of light (Dan Brady (https://commons.wikimedia.org/wiki/File:Indian_pigments.jpg), “Indian pigments”, https://creativecommons.org/licenses/by/2.0/legalcode)

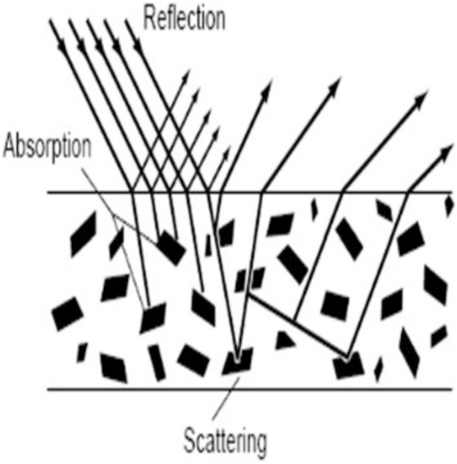


Fig. 8.17 Numerous interactions between light and pigments determine paint appearance

surface is partially reflected; the remaining light enters the binder and strikes the particles of pigment, which act like tiny mirrors and filters. If the particles are opaque, the light will be selectively reflected and absorbed. Transparent particles will reflect, absorb, and transmit incident light. These processes occur many times as the light makes its way through the binder (Fig. 8.17).

8.5 Painting Materials

Through the ages, master painters have worked with a variety of materials. Some readers of this book would already have studied the techniques of painting and will be quite familiar with them. Others, however, who are using this text to gain as an understanding of light and color, or to enhance their appreciation of the visual arts, may appreciate a brief discussion of materials in paintings.

Traditional paints consist of pigments plus a suitable binder. Encaustic paintings combine pigment with wax, fresco paintings combine pigment in aqueous solution with plaster, tempera paintings combine pigment with egg yolk, pastel paintings combine dry pigment with a weak solution of gum Arabic, watercolor paintings combine pigment with an aqueous solution of gum Arabic, and oil paintings combine pigments with oil. The pigment may be ground finer or coarser in one type of paint or another.

Painters over the centuries have been very attentive to the demands of particular materials. The composition of their paintings has often been adapted to best accommodate the materials used. Sometimes paintings incorporate more than one binder because the artist wishes to use different pigments, some of which are compatible with one binder but not with others. Painters often select materials to give a desired texture to their paintings. Most serious painters have carefully studied the works of the great masters and understand the materials they used. However, artists also experiment with new materials and develop new techniques to incorporate them.

In the twentieth century, science has given painters a number of new materials with which to work. Among them are polymer colors, acrylic colors, synthetic organic pigments, and luminescent pigments. Synthetic media have a number of advantages over traditional materials: they can be less expensive, they are fast drying, they are long lasting, they can be built up to greater thickness, they adhere to a wide variety of surfaces, and coloring agents other than pigments can be used with them. Although adopting new materials always calls for the painter to learn new skills, the new synthetic materials have probably made the techniques of painting easier for artists.

An in-depth examination of both traditional and synthetic painting media may be found in Appendix G.

8.6 Printing

Color printing in books and magazines makes use of both additive and subtractive color mixing. Before we discuss this topic, let us consider how black-and-white pictures are printed.

Halftone Printing

A photograph with a continuous range of brightness (from black to gray to white) is called a *continuous tone* in the printing trade. In contrast, the *halftone process* commonly used for printing photographs consists entirely of black dots on a white background, as shown in Fig. 8.18. To print a region of gray, the paper is printed

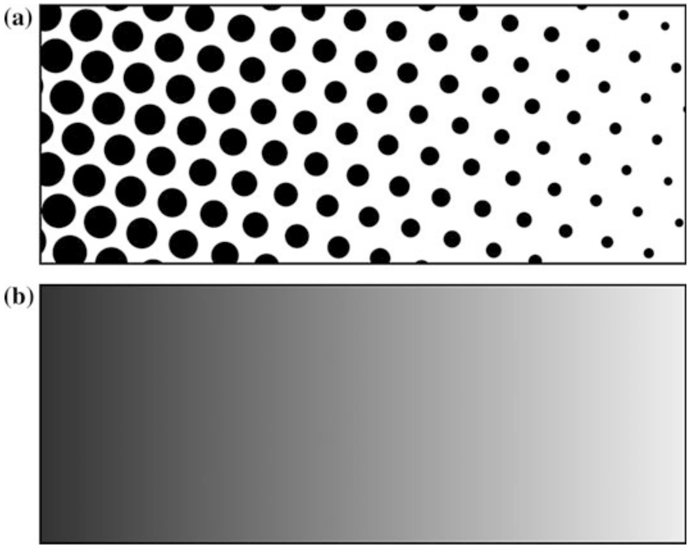


Fig. 8.18 **a** A halftone consists of black dots on a white background. **b** Very small dots are undetectable at normal viewing distance

with black dots of such a size and spacing that the area is half dots and half white space (hence the name *halftone*). If the dots are sufficiently small, visual fusion makes them undetectable at the normal viewing distance, and the area is seen as a uniform gray. These dots can be seen when a halftone-printed photograph is viewed with a magnifying lens.

Four-Color Printing

Most modern four-color printing procedures produce four screened positive films of the picture: one for the magenta parts, one for the yellow, one for the cyan, and one for black. (Theoretically, three should suffice, but experience has shown that printing inks do not perfectly represent subtractive primaries, so when the three colors are superimposed they produce dark brown rather than black.) Figure 8.19 shows an example of what is seen when looking at a printed color image through a magnifying (convex) lens.

When making the screened separations, the lines of dots are rotated by about 30° between one color and the next to avoid unwanted geometric dot patterns in the final plate. Because of the partial overlap of the dots, both subtractive and additive color mixing play a role. Where the dots overlap, the color is produced by subtractive mixing; where they are adjacent, additive (partitive) mixing applies.

A color photocopier or inkjet printer makes four copies of the original, the first three as viewed through yellow, cyan, and magenta filters. Yellow, cyan, magenta, and black toner or inks are applied to the paper in more or less continuous layers, so no dots are seen through a magnifying lens (unless the original was printed, in which case the colored dots may be copied, more or less).

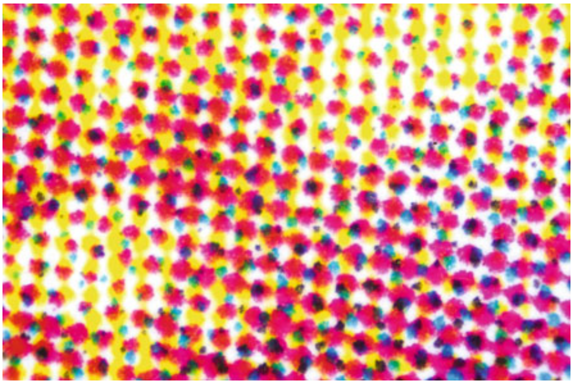


Fig. 8.19 Magnified four-color printing on white paper (Peter Hermes Furian/Shutterstock)

8.7 Colored Glass

Glass can be colored by the addition of chromium, manganese, iron, cobalt nickel, or copper ions. Ions are atoms that have gained or lost electrons so that they carry an electrical charge. In the case of the “transition metals” listed, the atoms have lost either two or three electrons so they carry a++ or +++ charge. These transition metal atoms have a partially filled shell of electrons (called the 3d shell) that have rather low excitation energies, and therefore they absorb in the visible region of the spectrum (see Sect. 7.2). In common soda-lime silica or window glass, for example, chromium (Cr+++) ions absorb in the red and blue regions of the spectrum and thus give a green color to the glass, whereas cobalt (Co+++) ions give glass a reddish-blue color.

Stained glass became an important art material in the Middle Ages in Europe during the building of the great cathedrals. The glass used in the great cathedral windows came from many shops, such as the Murano glassworks in Venice. The monk Suger, abbot of the monastery of Saint-Denis near Paris, made stained glass the centerpiece in rebuilding the monastery church, which in turn inspired its use in other great cathedrals at Chartres and elsewhere (see, e.g., Fig. 8.20).

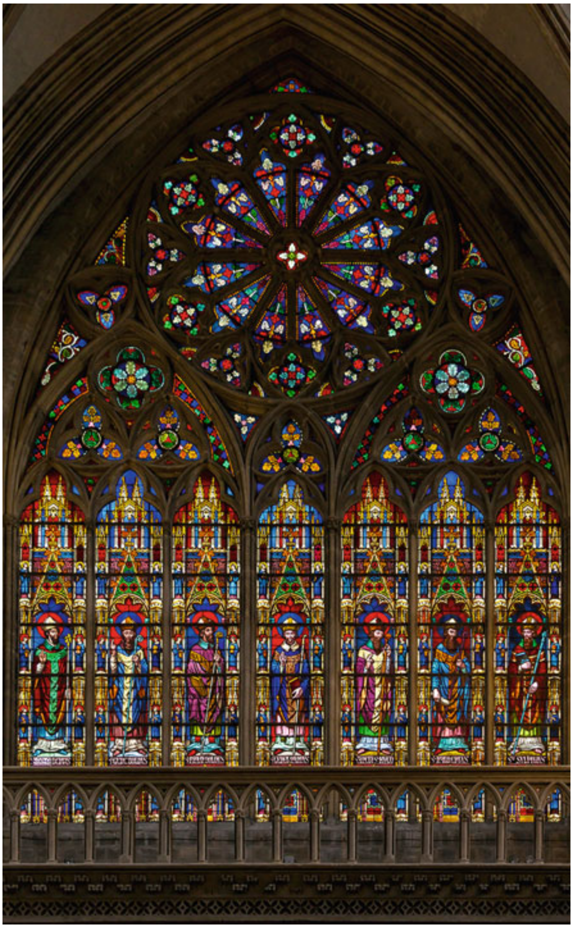


Fig. 8.20 Stained glass windows in the Cathedral of Bayeux, Calvados, Normandy, France (Public Domain via Wikimedia Commons)

The range of colors in glass that can be obtained with metal ions is somewhat limited in that it does not include red. Reds and yellows can be obtained by adding small particles of gold, copper, or silver to the glass. Such a suspension of one substance in another is called a *colloid*. When the metal particles in glass are smaller than 50 nm, they scatter light of short wavelengths more effectively than light of long wavelengths (Rayleigh scattering; see Sect. 1.5), so the light that passes through the glass tends to look red, like the color of the setting Sun. Gold and copper, which absorb in the blue and green, produce bright red; silver, which has only a weak absorption in the blue, produces a yellow color. Scattering may also arise from tiny air bubbles within the glass.

8.8 Glazes and Enamels

The hardening of wet clay by heating it to high temperatures has been known for many years. The resulting material is known as pottery. During the heat treatment, colors appear due to impurities depending on the conditions in the oven or kiln. For example, in a nearly airtight kiln allowing little oxygen to enter, iron-bearing clay (as found in ancient Greece) generally turns black due to the formation of magnetite (Fe_3O_4) at temperatures around 1000°. If air is allowed to circulate, however, the iron combines with more oxygen to form hematite (Fe_2O_3), and the color changes to reddish-brown.

Before firing, a design can be applied with a water paint (a *slip*) bearing particles of materials such as iron oxide or manganese oxide. Various slips and the underlying clay absorb oxygen at different rates, and by careful firing, the various slips can be altered to produce different colors.

An important use of glass, both clear and colored, is in producing a *glaze* for pottery. Glass is ground to a fine powder, mixed with a liquid binder, and painted on the pottery. During firing, the glaze melts and fuses together to form a thin liquid layer that solidifies on cooling to form a coat of solid glass. By using powdered glass of various colors, a pattern can be worked into the glaze. For tableware, the glaze forms a smooth glass surface that is more hygienic than porous, unglazed pottery. However, lead glass should be avoided, since the lead can be leeched out of the glaze.

A thin layer of glass fused to a metal, called *enamel*, can provide decoration and prevent corrosion. As in glazing, a powdered glass suspended in a liquid binder is spread over the metal surface, and the object is fired briefly to fuse the powder to the surface. The final color of the enamel is very sensitive to the firing conditions and can be dramatically affected by impurities at the surface of the metal. Porcelain enamel is commonly applied to iron for kitchenware, sinks, and bathtubs.

8.9 Light as the Medium

> *It's not about light or a record of it, but it is light. Light is not so much something that reveals, as it is itself the revelation.*
>
> —Artist James Turrell

There is possibly no element in the creation and appreciation of art more important than light. Artists have long manipulated light to establish both mood and meaning as well as provide visual information regarding shape and depth. In the early twentieth century, the role of light in art expanded dramatically when it was realized that light itself could be used as an artistic medium. This understanding ushered in what is commonly known alternately as light art, light sculpture, or luminism.

Hungarian artist László Moholy-Nagy is considered to be the first to use light as a sculptural element. His 1930 creation, titled *Light-Space Modulator*, was a kinetic sculpture consisting of 70 flashing lights mounted on a rotating platform. Later, another light sculpture pioneer, American abstract artist Charles Biederman, used red, blue, and yellow fluorescent light tubes to illuminate a static, partially painted wood and glass geometric relief construction he titled *#9, New York, 1940*. While artificial lighting was integrated into the piece, it was not the sole medium.

In the 1960s, Dan Flavin started using commercially produced lamps and fixtures as the only components in his art. His first work, *Diagonal of May 25, 1963*, consisted of a single yellow fluorescent tube mounted at an angle on a wall. This seminal work made light both the subject and the medium. Flavin went on to create dozens of additional light sculptures and installations, including the one shown in Fig. 8.21 In his *Structure and clarity,* Flavin expanded the use of fluorescent tubes using a palette of red, blue, green, pink, and yellow.

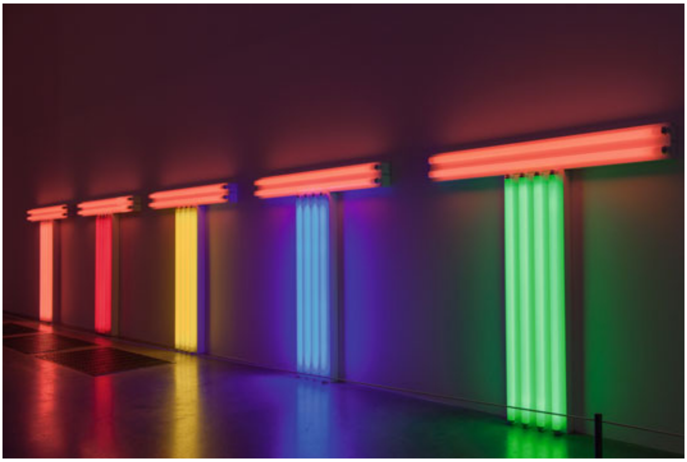


Fig. 8.21 Dan Flavin's *Structure and clarity* (Grand Parc—Bordeaux, France from France (https://commons.wikimedia.org/wiki/File:Dan_Flavin_-_Structure_and_clarity_-_Tate_Modern_Museum_London_(9671384931).jpg), "Dan Flavin—Structure and clarity—Tate Modern Museum London (9671384931)", https://creativecommons.org/licenses/by/2.0/legalcode)

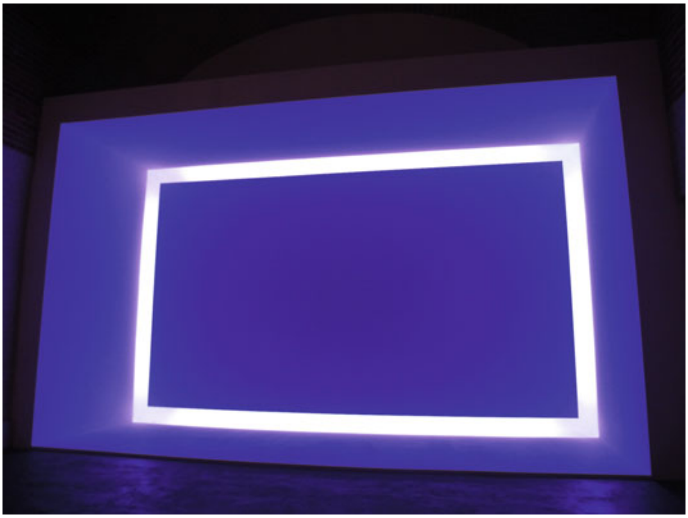


Fig. 8.22 James Turell's *Raemar Magenta* (Mikenorton (https://commons.wikimedia.org/wiki/File:Raemar_Magenta.JPG), https://creativecommons.org/licenses/by-sa/4.0/legalcode)

Later, artists who include Robert Irwin, Bruce Nauman, Doug Wheeler, and James Turrell began investigating the relationship among the viewer, light, visual perception, and space. These artists are considered to be part of the so-called "Light and Space" movement that flourished in California during the 1960s. Like Flavin, many in this influential group incorporated fluorescent as well as neon lighting in their works.

Of the light artists, Turrell's body of work is perhaps among the most expansive and diverse. Using only light and environment, Turrell's creations run the gamut from extremely simple, yet powerfully evocative, light projections to large-scale environmental works. One of his earlier works, *Raemar Magenta*, is shown in Fig. 8.22. With a focus on perceptual experiences, many of Turrell's installations allow, in his words, "visitors to enter the light." His most ambitious work is *Roden Crater* in Arizona, where he is transforming an extinct volcano into a celestial observatory. When completed, visitors will enter the volcano, where they will experience the nexus of light, space, and astronomical events.

8.10 Summary

Three colors that can produce white light (such as red, green, and blue) are called primary colors. Any two colors that produce white light when added together are called complementary. The complement of a primary color is called a secondary color. Additive relationships between colors can be represented on Newton's color circle. Additive mixing may be obtained by superposition, by partitive mixing, or through visual persistence.

Yellow, magenta, and cyan are considered the three subtractive primaries; combining filters (or pigments) of these colors will generally produce black. The transmittance curve of a filter completely describes its effect, but filters with different transmittance curves can produce the same hue. A spectral filter produces greater saturation than a nonspectral one but at the expense of brightness.

Dyes and paint pigments are the two main sources of color available to the artist; however, some artists use light itself as an artistic medium.

◆ Review Questions

1. The secondary colors, cyan, magenta, and yellow, can each be obtained by subtracting a primary color from white light. Which primary color is subtracted in each case?
2. **a.** What is meant by a spectral color?
   b. Which two of the secondary colors can also be spectral colors?
3. What are the two main sources of color available to the artist? How are they different?
4. What is a lake? Describe an application for lakes.
5. Describe three methods of additive color mixing.
6. What is a neutral density filter?
7. Explain the difference between monochromatic, spectral, and nonspectral filters.
8. List some of the advantages of using synthetic painting media.

▼ Questions for Thought and Discussion

1. White light first passes through a magenta filter, then a cyan filter. Describe the color of the light that emerges from the filter combination.
2. Is it possible to produce black using additive color mixing? Explain your answer.
3. Explain why colored fringes appear around objects when viewed through a lens. This defect is called chromatic aberration, a problem that prompted Newton to investigate light and color.

● Experiments for Home, Laboratory, and Classroom Demonstration

Home and Classroom Demonstration

1. **Mixing colored light I**. The eye retains an image for a short time after the removal of the stimulus that produced it. It is therefore possible to combine colors by presenting them to the eye in rapid succession. If, for example, a flash of red light impinges on the retina, the sensitive cones that are activated by the light continue sending signals to the brain for a fraction of a second. If a source

of green light strikes the retina within this time, the brain will perceive yellow, the additive combination of red and green. A device referred to as the color mixing turbine provides a simple way to achieve additive color mixing. To construct a color mixing turbine, bend two opposite corners of a small black cardboard square in opposite directions to produce "turbine blades." Attach a green sticker to the center of one side of the card. Repeat with a red sticker to the opposite side. Gently hold the card's two unbent corners between your index finger and your thumb. Blow on the blades to make the turbine spin. The alternating colors act as flashing red and green lights, the combination of which produces the sensation of yellow.

2. **Mixing colored light II**. To convince yourself that only the three additive primary colors are responsible for the myriad hues you see on your television screen or computer monitor, hold a magnifying glass close to the screen. Once the proper viewing distance is achieved, you will see an array of small red, blue, and green dots or rectangles. If you are watching a television program, note that the intensity of each colored dot is constantly changing. Why?
3. **Selective reflection**. The color of an object depends in part on the color of the light shining on it. To observe this phenomenon, all you need is a cardboard box with a lid (a shoebox is perfect) and sheets of colored cellophane (red and green work well). Cut a square opening, roughly 4″ × 4″, in the box lid. Cover the opening with a single sheet of cellophane. Finally, cut a viewing hole in one end of the box. You are now ready to experiment. Place various colored objects in the box and examine their appearance under the colored light. How do the objects appear? Do some of them look strange? Why does the color of some objects appear to change when viewed in the box?
4. **Subtractive color mixing I: Overlapping filters**. Hold cyan and magenta filters together so that white light passes through both filters before entering the eye. Carefully observe the color that is visible through overlapping filters. Repeat this procedure with combinations of cyan, magenta, and yellow filters. What do you see when you overlap all three filters?
5. **Subtractive color mixing II: Combining inks**. Place two drops of yellow ink and two drops of magenta ink on a sheet of wax paper. After slowly mixing the two inks together with a Q-tip, use the Q-tip to draw a line or other figure on a piece of white paper. What color appears? Repeat the procedure with combinations of yellow and cyan inks, then cyan and magenta inks. Finally, mix two drops of all three inks together. Each time use a clean Q-tip. What conclusions can you make regarding the various combinations of the subtractive primaries cyan, magenta, and yellow? (Note: Dr. Ph. Martin's yellow, magenta, and teal Bombay India Inks work well.)
6. **Viewing paintings in colored light**. Observe the effect of illuminating paintings with various colors of light.

Laboratory (See Appendix J)

8.1 Exploring Color.
8.2 Mixing Pigments: Subtractive Color Mixing

Glossary of Terms

complementary colors (of light) Two colors that produce white light when added together.

complementary colors (of pigment) Two colors that produce black when added together.

dye A solution of molecules that selectively absorbs light of different colors.

enamel A thin layer of glass fused to a metal.

glaze A thin layer of glass covering the surface of pottery.

halftone process Printing with black dots of various sizes to represent shades of gray.

hue Color name; what distinguishes one color from another.

lake Coloring agent consisting of alumina particles covered with dye.

monochromatic filter Filter that allows only one wavelength (color) to pass through.

neutral density filter Gray filter that reduces the intensity of light without changing its spectral distribution (color).

Newton's color circle Three primary colors arranged around a circle with the complementary secondary colors directly opposite.

paint pigments Color-absorbing powders suspended in a medium such as oil or acrylic.

primary colors (additive, of light) Three colors that can produce white light.

primary colors (subtractive, of filters or pigments) Three colors that can produce black.

saturation Purity of a color; spectral colors have the greatest saturation; white light is unsaturated.

spectral filter Filter that passes a distribution of wavelengths of light.

spectral reflectance curve Graph indicating the portion of light reflected at each wavelength.

spectroscope Instrument that measures the power (in watts) of light at each wavelength.

spectral power distribution (SPD) Power of light as a function of wavelength.

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