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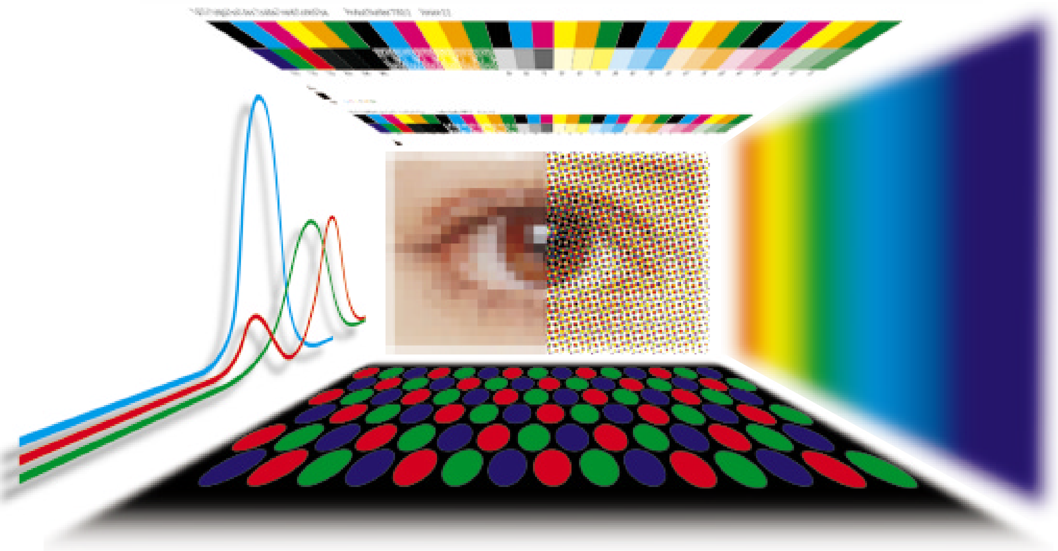
The COLOR GUIDE and Glossary



Communication, Measurement, and Control for Digital Imaging and Graphic Arts

The COLOR GUIDE and Glossary

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1 Color Communication

Color communicates. Color sells. Color is the sizzle that drives the sale of virtually every consumer product in the world. It evokes a wide range of emotions that draw the buyer to the product. As design, graphics, and imaging professionals, we know that color is a crucial part of the selling process because it is such an important part of the *buying decision.* If we use color effectively in the manufacturing and marketing of an item, potential buyers will perceive added value in that product.

These GATF test images demonstrate colors that must be reproduced with careful precision. If the color of skin tones, sky blue, grass green, or food items are "off" by even a small margin, the appearance of the entire image will be adversely affected.

To use color effectively, it must be kept under tight *control.* The color workflow begins with the designer's ideas and the customer's specifications. From there, these colors must be communicated among several different individuals who will render and reproduce the colors on many different devices. At each stage of production, *output* from the previous step becomes the *input* for the next process. Every exchange brings the color into a new color space—from photographic film to monitor RGB to CMYK process proofing and printing on a variety of systems. And every evaluation is made by a different viewer under new viewing conditions.

So, how do we ensure that our original ideas and specifications will remain intact throughout this complicated process? This book is designed to answer that very question. In short, the answer is *color measurement*—if you can *measure* color, you can *control* it. The remainder of this booklet explains the fundamentals of color communication, measurement, and control.

The Challenge: Color Communication

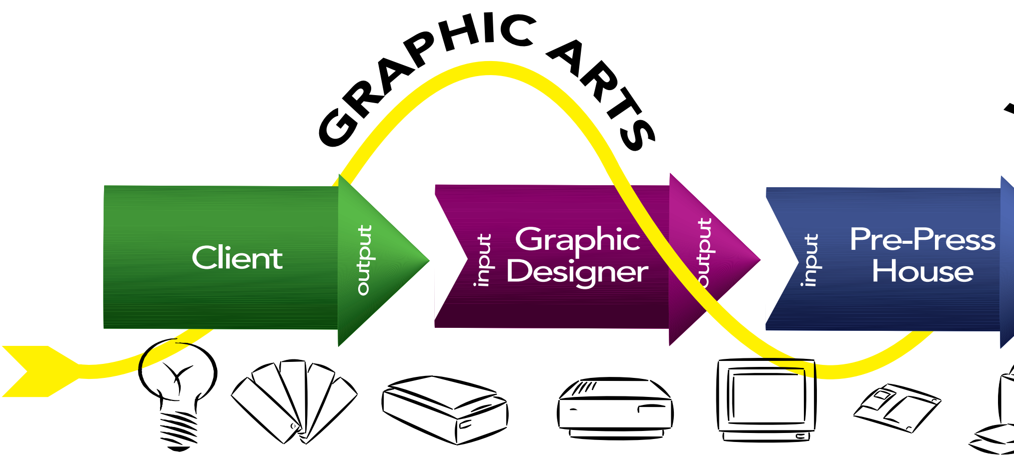
Consider the many different individuals who "pass the baton" of responsibility for keeping the customer's color specifications intact:

- **Content Specifier/Client** Defines message; determines image concept; provides general or specific color and paper specifications.
- **Graphic Designer/Photographer** Provides image, art, and page files; and printed or digital color specifications.
- **Pre-Press Service Provider** Provides final color-separated films; color break information; printed or digital color specifications.
- **Printing Ink Supplier** Provides inks that meet color specifications; considers paper specification.
- **Printing Company** Provides final printed piece; meets color specifications.

Each step in the color reproduction process adds value and content to the message. Good color specification ensures that each process provides accurate color content based on the input received.

As we strive to create dazzling, high-quality color documents and designs, we struggle to control color at each production phase. Each viewing situation presents its own interpretation of the same color. For example:

- Our original scene contains a wide range of natural, vivid colors.
- A photograph of the scene captures much of the scene's color; however, some of the dazzling tones are lost when the image is scanned into RGB data. Still more colors are lost or changed when the scan is displayed on a monitor—and the scene appears slightly different on different monitors.
- As we move our artwork between imaging, illustration, and layout programs, the colors are specified in different ways. For example, specifying 87% magenta /



91% yellow produces a slightly different color in Photoshop™, FreeHand™, and QuarkXPress®.

- When we print our artwork, the colors get color-separated from RGB data into CMYK data. The colors are interpreted a bit differently on different devices—on our laser copier, our trade shop's proofing system, and on press.

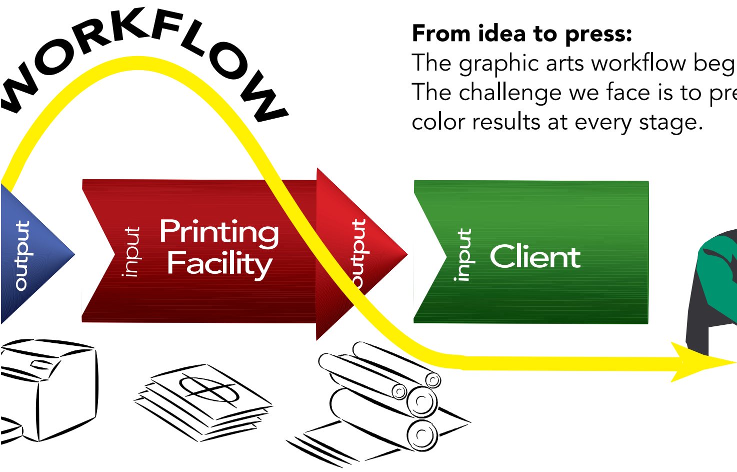
- When we check our output, we view the colors under different lighting conditions that affect color appearance in different ways. Also, different individuals perceive colors based on their own vision skills and memory.

The common question throughout this process is: which device is telling the *truth*? Unfortunately, no individual viewers, programs, or devices can reveal the true identity of a color. They simply perceive the color's appearance, which can be affected by lighting and other factors.

The Solution: Color Measurement and Control

Measurement is the key to total production control. Consider this: we measure size in inches or millimeters; weight in pounds and grams; and so on. These scales allow us to establish precise measurement standards that can be *repeated* in the production process. This ensures that all manufactured items are *identical* and within our quality tolerances. Using measured color data, we can do the same for color—we can monitor color at each stage of production and check the "closeness"of color matches using repeatable, standardized numerical data. So, what properties of colors allow them to be discretely identified and measured?

Let's find out by examining these properties—how color happens in nature and in our minds; how it is reproduced on screen and on paper; and how color can be *communicated* as reflectance values (*spectral data*) and as three-dimensional values (*tristimulus data*).

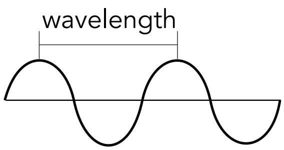


From idea to press:
The graphic arts workflow begins and ends with the customer. The challenge we face is to present the customer with consistent color results at every stage.

UNDERSTANDING COLOR

To help you clearly understand how color is measured, we should first study the fundamentals of color's physical and physiological properties.

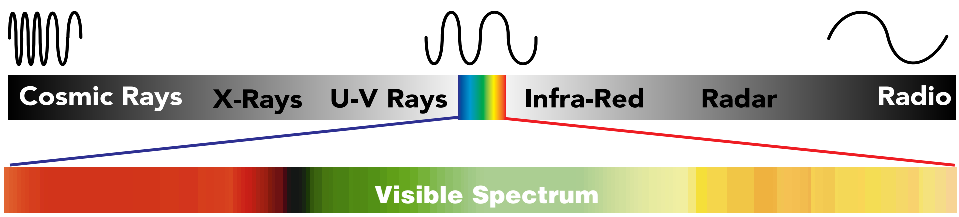
Color results from an interaction between *light, object*, and the *viewer*. It is *light* that has been modified by an *object* in such a manner that the *viewer*—such as the human visual system—perceives the modified light as a distinct color. All three elements must be present for color *as we know it* to exist. Let's examine color's origins in more detail by first studying *light*.



Light—Wavelengths and the Visible Spectrum

Light is the visible part of the *electromagnetic spectrum*. Light is often described as consisting of waves. Each wave is described by its wavelength - the length from wave crest to adjacent wave crest. Wavelengths are measured in nanometers (nm). A nanometer is one-millionth of a millimeter.

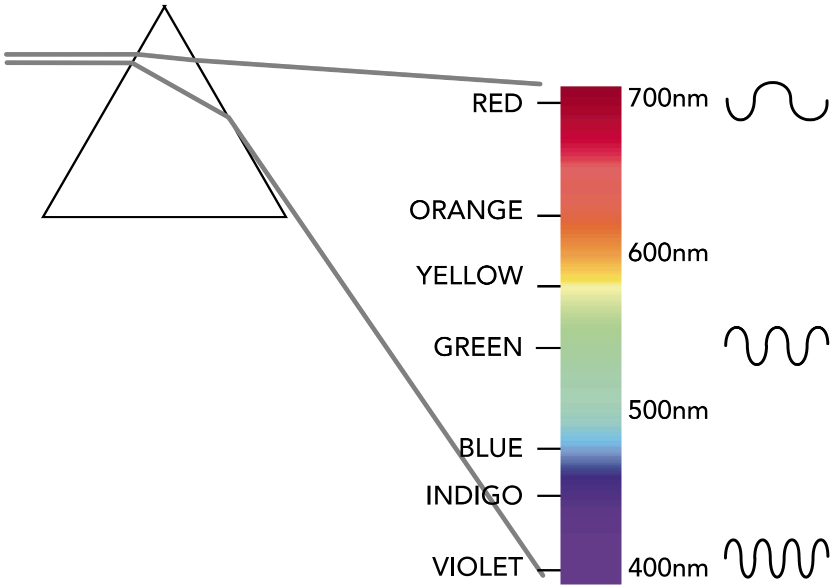
The region of the electromagnetic spectrum visible to the human eye ranges from about 400 to 700 nanometers. This amounts to a mere slice of the massive electro-magnetic spectrum. Although we can't see them, we use many of the invisible waves beyond the visible spectrum in other ways—from short-wavelength x-rays to the broad wavelengths that are picked up by our radios and televisions.



Our eyes have light sensors that are sensitive to the visible spectrum's wavelengths. When light waves strike these sensors, the sensors, the senors send signals to the brain. Then, these signals are perceived by the brain as a particular color. Exactly which color is perceived depends on the composition of wavelengths in the light waves. For example, if the sensors detect all visible wavelengths at once, the brain perceives *white* light. If no wavelengths are detected, there is no light present and the brain perceives *black*.

Now we know how our eyes and brain respond to the presence of *all* visible wavelengths or *no* wavelengths. Next, let's examine how our vision system responds to each *individual* wavelength.

Passing a beam of white light through a prism disperses the light so that we can see how our eyes respond to each individual wavelength. This experiment demonstrates that different wavelengths cause us to see different colors. We can recognize the visible spectrum's dominant regions of red, orange, yellow, green, blue, indigo, and violet; and the "rainbow" of other colors blending seamlessly in between.



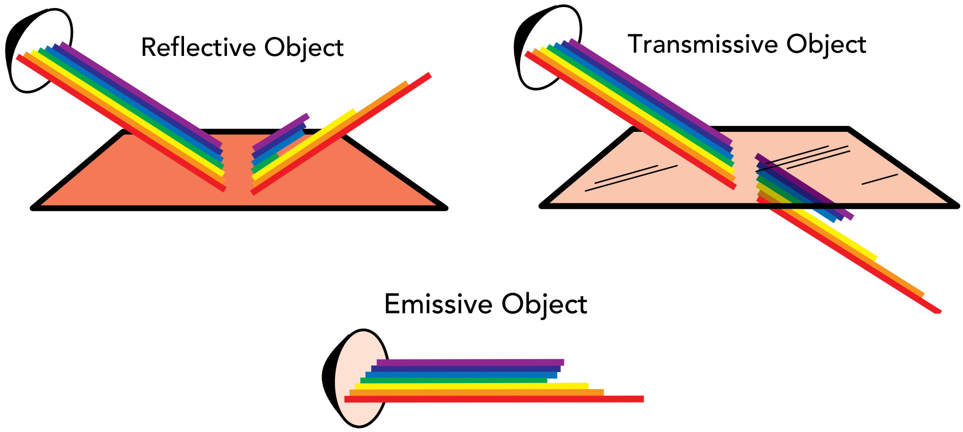
When our visual system detects a wavelength around 700nm, we see "red;" when a wavelength around 450-500nm is detected, we see "blues;" a 400nm wavelength gives us "violet;" and so on. These responses are the basis for the billions of different colors that our vision system detects every day.

However, we rarely see *all* wavelengths at once (pure white light), or just *one* wavelength at once. Our world of color is more complex than that. You see, color is not simply a *part* of light—it *is* light. When we see color, we are seeing light that has been *modified* into a new *composition* of many wavelengths. For example, when we see a red object, we are detecting light that contains mostly "red" wavelengths. This is how all objects get their color—by modifying light. We see a world full of colorful objects because each object sends to our eyes a unique composition of wavelengths. Next, let's examine how *objects* affect light.

Objects—Manipulating Wavelengths

When light waves strike an object, the object's surface *absorbs* some of the spectrum's energy, while other parts of the spectrum are *reflected* back from the object. The modified light that is reflected from the object has an entirely new composition of wavelengths. Different surfaces containing various pigments, dyes, and inks generate different, unique wavelength compositions.

Light can be modified by striking a *reflective* object such as paper; or by passing through a *transmissive* object such as film or a transparency. The light sources themselves - emissive objects such as artificial lighting or a computer monitor - also have their own unique wavelength composition.



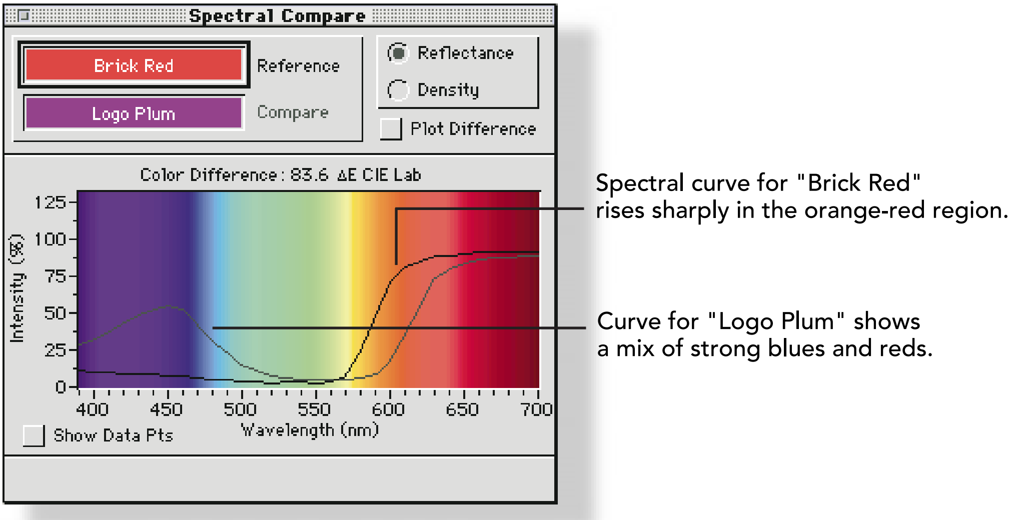
Reflected, transmitted, or emitted light is, in the purest of terms, "the color of the object." There are as many different colors as there are different object surfaces—each object affects light in its own unique way. The pattern of wavelengths that leaves an object is the object's *spectral data*, which is often called the color's "fingerprint." Spectral data results from a close examination—or *measurement*—of each wavelength. This examination determines the percentage of the wavelength that is reflected back to the viewer—its *reflectance intensity*.

You can visually examine a color's spectral properties by plotting its measurement data as a *spectral curve*. This type of data can be gathered only by using a spectrophotometer such as X-Rite's Digital Swatchbook®, model 938 Spectrophotometer, Colortron, DTP41, or Auto-Tracking Spectrophotometer (ATS) system.

Spectral Data

Spectral data can be plotted as a spectral curve, providing a visual representation of a color's fingerprint. Light's wavelengths and reflectance intensity provide two absolute points of reference for plotting a curve: the 300 nanometers of different wavelengths comprise the horizontal axis, and the level of reflectance intensity comprises the vertical axis.

Using ColorShop's Spectral Compare tool, you can compare a color's curve shape—where it rises and dips—to the points along the wavelength axis.



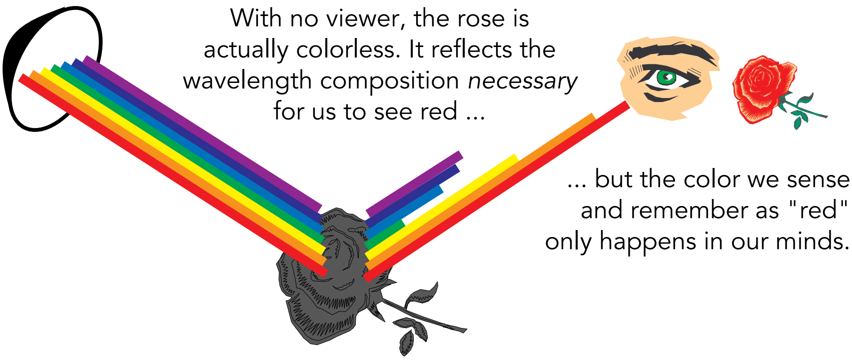
To compute spectral data, spectrophotometers examine a number of points along the wavelength axis (Digital Swatchbook, for example, reports 31 points spaced 10nm apart), then determine the amount of reflectance intensity at each wavelength. *This is the most complete and infallible description of a color you can achieve.* Later, we'll demonstrate spectral data's power and precision further as we compare it with other color models and specification methods.

So far, we've studied *light*; *objects*; how objects affect light to generate different colors; and how a spectrophotometer can be used to directly *measure* how different objects affect light. To completely define color *as we know it*, we must conclude by studying the *viewer*—the human eye and other devices that sense or render color.

Viewer—Sensing Wavelengths as "Color"

For our visual palette of colors to exist, all three elements of color—*light*, *object*, and *viewer*—must be present. Without *light* there would be no wavelengths; without *objects* there would be only white, unmodified light; and without the *viewer* there would be no sensory response that would recognize or register the wavelengths as a unique "color."

There is a well-known riddle that asks: "If a tree falls in the woods and no one is there to hear it, does it make a sound?" Actually, a similar question can be asked in regards to color: "If a red rose is not seen, does it have color?" The answer—which may surprise you—is *no*. Technically, color *is* there in the form of wavelengths (the spectral data). However, the color we know as "red" only happens in our minds, after our visual sensory system has responded to those wavelengths.



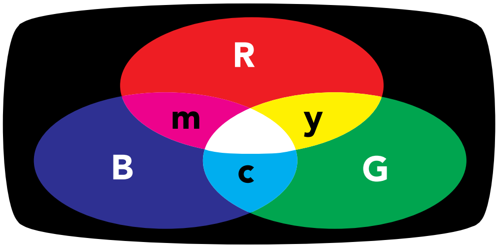
The basis for human vision is the network of light sensors in our eyes. These sensors respond to different wavelengths by sending unique patterns of electrical signals to the brain. In the brain, these signals are processed into the sensation of *sight*—of light and of color. As our memory system recognizes distinct colors, we then associate a name with the color.

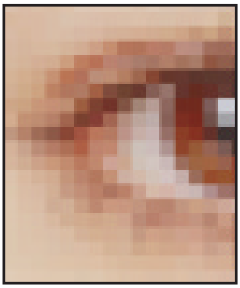
So, do our brains also examine discrete wavelength information and plot curves for every color we see? Not exactly. The human visual system must work far too quickly to do all that, given the deluge of new wavelength information that it receives every second. Instead, this system's miraculous design uses a more efficient method for "mass-processing" wavelengths. It breaks the visible spectrum down into its most dominant regions of *red*, *green*, and *blue*, then concentrates on these colors to calculate color information.

RGB—Color's Additive Primaries

By mixing these dominant colors—called the *additive primaries*—in different combinations at varying levels of intensity, the full range of colors in nature can be very closely simulated. If the reflected light contains a mix of pure red, green, and blue light, the eye perceives white; if no light is present, black is perceived. Combining two pure additive primaries produces a *subtractive* primary. The *subtractive primaries* of cyan, magenta, and yellow are the opposing colors to red, green, and blue.

When two additive primaries overlap, a subtractive primary is produced. Where all three are combined, white light is produced.

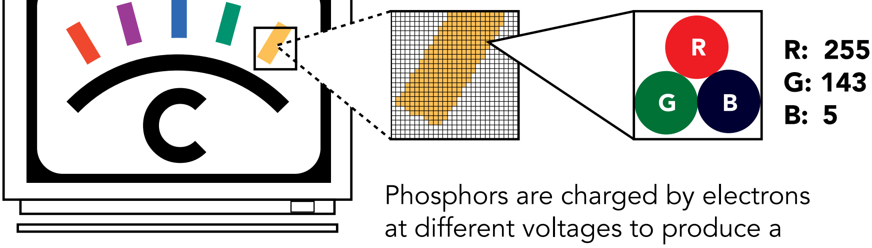




The human eye's three-value color system has been imitated and exploited—by inventors of color scanners, monitors, and printers. The color rendering methods used by these devices are based directly on our response to stimuli of red, green, and blue light.

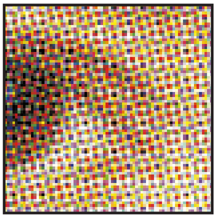
Screen is coated with microscopic pixels.

Each pixel contains RGB phosphors.



Phosphors are charged by electrons at different voltages to produce a range of different colors.

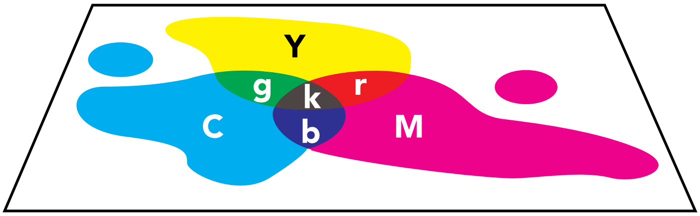
Like the human eye, these devices must also process a large amount of color information at once—on screen or on paper. In logical fashion, these devices imitate the eye's response to the additive primaries to create a colorful illusion: For example, a monitor blends varying intensities of red, green, and blue light at each of its tiny pixels. These pixels are so small and tightly packed that the eye's RGB response is "fooled" into the perception of many different colors when really there are only three.



CMY and CMYK—The Subtractive Primaries

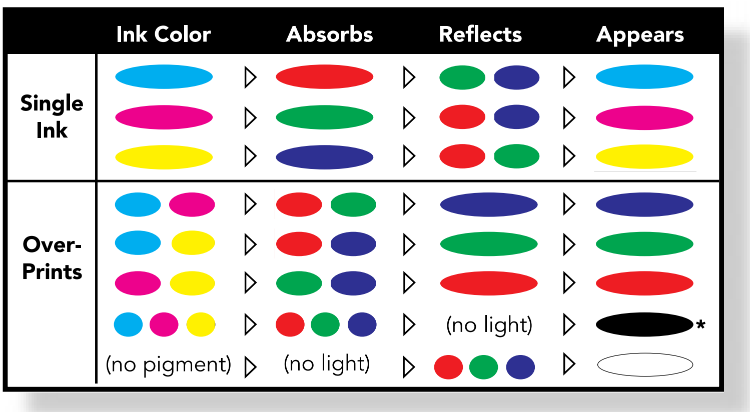
Monitors and scanners can employ the additive color system because they are *emissive* devices—they can directly *add* red, green, and blue light to darkness. *Printers*, on the other hand, must render colors on paper and other substrates, so they must work with *reflected* light. To do this, printers employ the opposing *subtractive* primaries of cyan, magenta, and yellow.

When two subtractive primaries overlap, an additive primary is produced.



****Theoretically, when all three are combined, black is produced. In actual practice, using cyan, magenta, and yellow inks typically produces a muddy gray. For this reason, pure black ink is added as a fourth colorant in process printing to ensure crisp, solid black for text and other important details; and to improve the overall tonal range of process printing.***

In the visible spectrum, *cyan* is directly opposed to red; *magenta* is the opposite of green; and *yellow* is the opposite of blue. When cyan, magenta, and yellow pigments are deposited on a white, reflective substrate, each completely absorbs—or *subtracts*—its opposing counterpart from the oncoming white light. For this reason, the printing process uses cyan, magenta, and yellow inks to control the amount of red, green, and blue light that is reflected *from* white paper.



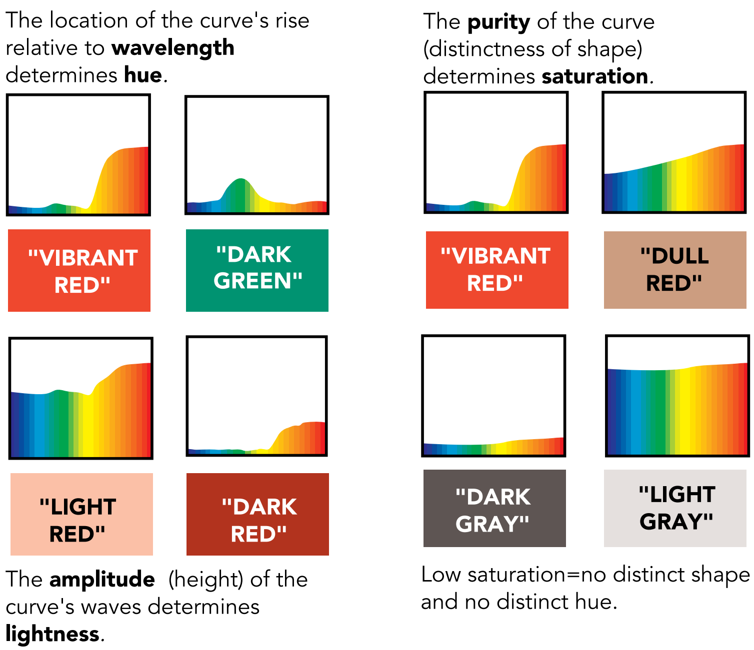
These colors are printed on paper as separate layers of halftone dot patterns. The illusion of different colors and tones is created by varying the size, balance, and angle of the dots. The effects of varying dot sizes is similar to the varying intensities of a monitor's red, green, and blue phosphors.

This diagram demonstrates how the subtractive primaries remove their additive counterpart from light to produce the appearance of a color:

HSL—The Three Dimensions of Color

So far, we've learned that color consists of complex wavelength information, and that the human eye, monitors, and printers, convert this complex information into three-value systems of primary colors in order to simplify processing and rendering of that information. Another way to simplify color description is to describe its three attributes or "dimensions:"

- **Hue**—its basic color, such as red, pink, blue, or orange.
- **Saturation**—its vividness or dullness.
- **Lightness**—its brightness or darkness.



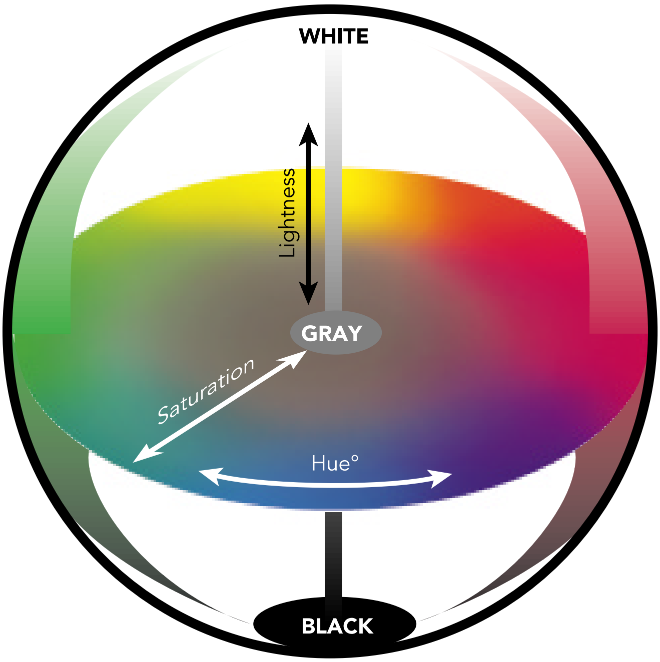
Light waves also have three attributes that directly affect the attributes of hue, saturation, and lightness. Of course, wave*length* determines the color's *hue*; wave *purity* determines *saturation*; and wave *amplitude (height)* determines *lightness*.

Spectral curves demonstrate the relationship between wave attributes and the way we perceive these attributes.

Vibrant, colorful objects reflect a distinct part of the spectrum at high intensity; objects that are near-white or light gray reflect most of the spectrum uniformly and at high intensity; dark gray, dark brown, and black objects *absorb* most of the spectrum's energy; and so on.

Color Space—Mapping Color's Dimensions

Hue, saturation, and lightness demonstrate that visible color is three-dimensional. These attributes provide three coordinates that can be used to "map" visible color in a *color space.* The early-20th Century artist A.H. Munsell—creator of the *Munsell Color Charts*—is credited as a pioneer of intuitive three-dimensional color space



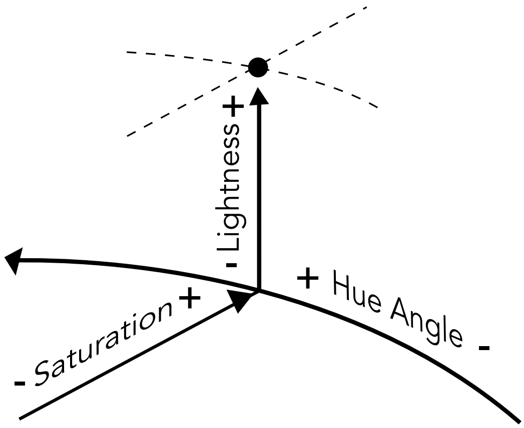
descriptions. There are many different types of color spaces that are based on or resemble Munsell's designs.

Basically, a color space based on hue, saturation (or *chroma*), and lightness (or *value*) uses cylindrical coordinates. Lightness is the center vertical axis and saturation is the horizontal axis that extends from the lightness axis. Hue is the *angle* at which the saturation axis extends from the lightness axis.

We can apply the relationship between wave attributes and color attributes to a three-dimensional color space. Wave *amplitude* determines a color's position on the lightness axis; wave *purity* determines its location on the saturation axis; and *wavelength* determines hue angle. Around the "equator" lie vibrant, pure hues. As the hues blend together toward the center, they become less pure and lose saturation. On the vertical axis, colors of different hue and chroma become lighter or darker. The lightness extremes of white and black lie at the "poles." And of course, at the center of it all lies neutral gray—where white, black, and all hues meet and blend together.

Tristimulus Data

A color space can be used to describe the range of visible or reproducible colors—or *gamut*—of a viewer or device. This three-dimensional format is also a very convenient way to compare the relationship between two or more colors. Later, we'll see how we can determine the perceptual "closeness" of two colors by the



distance between them in a color space. Three-dimensional color models and three-valued systems such as RGB, CMY, and HSL are known as *tristimulus data.*

Locating a specific color in a tristimulus color space such as RGB or HSL is similar to "navigating" around a city using a map. For example, on the HSL color space "map," you first locate the intersection where the Hue *angle* meets the Saturation *distance.* Then, the Lightness value tells you what "floor" the color is located on: from deep below ground (black) to street level (neutral) to a high-rise suite (white). In many applications, the intuitiveness of tristimulus color descriptions makes them a convenient measurement alternative to complex (yet more complete and precise) spectral data. For example, instruments called *colorimeters* measure color by imitating the eye to calculate amounts of red, green, and blue light. These RGB values are converted into a more intuitive three-dimensional system where relationships between several color measurements can be easily compared.

However, any system of measurement requires a *repeatable* set of standard scales. For colorimetric measurement, the RGB color model cannot be used as a standard because it is not repeatable—there are as many different RGB color spaces as there are human viewers, monitors, scanners, and so on (it is, as we'll discuss later, *device-dependent*). For a set of standard colorimetric measurement scales, we turn to the renowned work of the *CIE*—the *Commission Internationale d'Eclairage*.

Having explored the measurable properties and attributes of color, let's now study the established CIE standards upon which most industrial color communication and measurement is based.

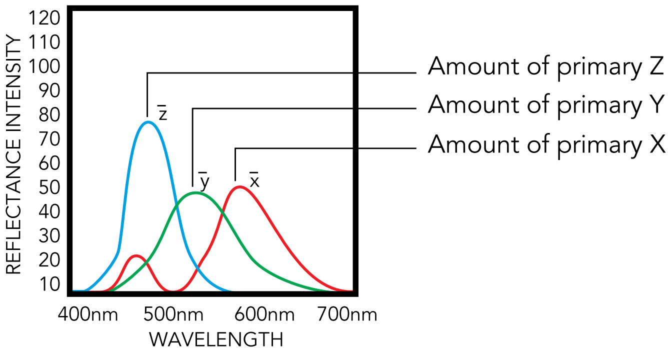
THE CIE COLOR SYSTEMS

In 1931, the *CIE* established standards for a series of color spaces that represent the visible spectrum. Using these systems, we can compare the varying color spaces of different viewers and devices against *repeatable standards*.

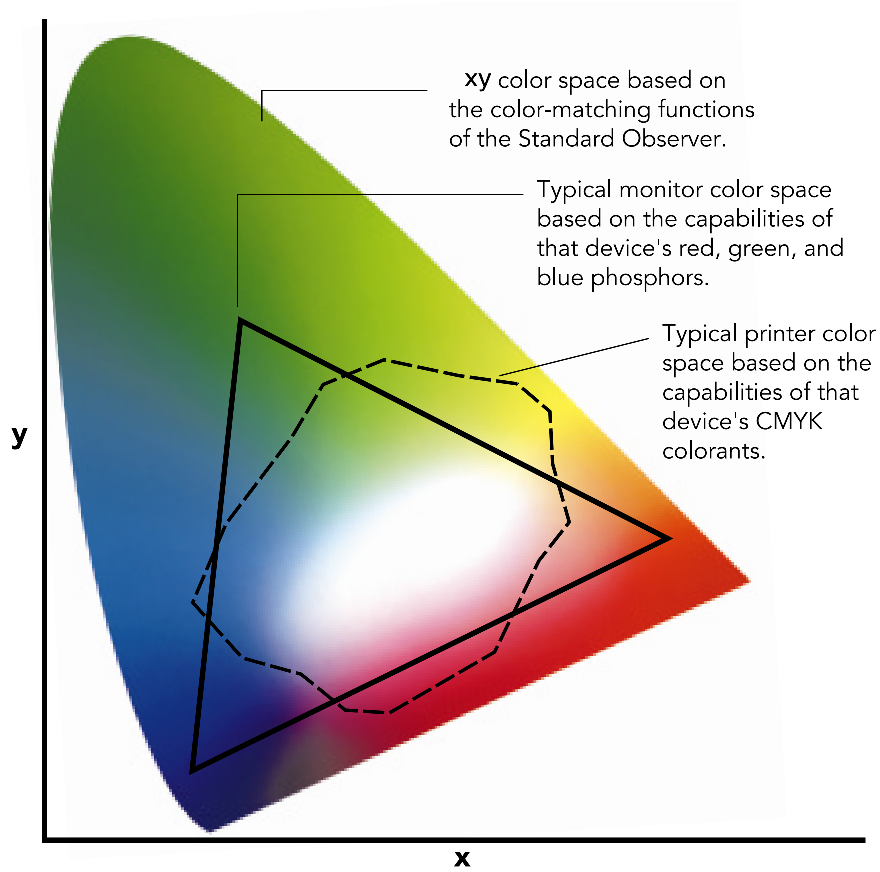
The CIE color systems are similar to the other three-value models we've discussed in that they utilize three coordinates to locate a color in a color space. However, the CIE spaces—which include CIE XYZ, CIE L*a*b*, and CIE L*u*v*—are *device-independent*, meaning the range of colors that can be found in these color spaces is not limited to the rendering capabilities of a particular device, or the visual skills of a specific observer.

CIE XYZ and The Standard Observer

The basic CIE color space is *CIE XYZ*. It is based on the visual capabilities of a *Standard Observer*, a hypothetical viewer derived from the CIE's extensive research of human vision. The CIE conducted color-matching experiments on a number of



subjects, then used the collective results to create "color-matching functions" and a "universal color space" that represents the average human's range of visible colors. The color matching functions are the values of each light primary—red, green, and blue—that must be present in order for the average human visual system to perceive all the colors of the visible spectrum. The coordinates *X*, *Y*, and *Z* were assigned to the three primaries.



The xy chromaticity diagram has a "natural" shape because we are more sensitive to small color changes between purples and reds than we are to changes between greens and yellows.

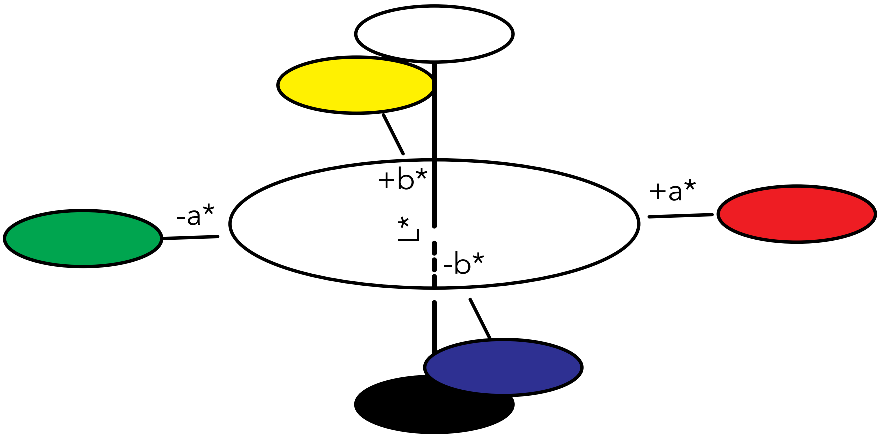
You can see how the upper left of the diagram "stretches out" in the greens and yellows, white, reds, and purples are packed tightly together.

From these XYZ values, the CIE constructed the *xyY Chromaticity Diagram* to define the visible spectrum as a three-dimensional color space. The axes of this color space are similar to the HSL color space; however, the xyY space could not be described as cylindrical or spherical. The CIE found that we do not see all colors uniformly, and therefore the color space they developed to "map" our range of vision is a bit skewed.

On our rendering of the xy diagram, we have demonstrated the limitations of color spaces developed using coordinates of monitor RGB and printer CMYK. To lead us into our next discussion, we must also point out that the RGB and CMYK gamuts shown here are not standard gamuts. These descriptions would change for every individual device. However, the XYZ gamut is a device-independent, *repeatable* standard.

CIE L*a*b*

The ultimate goal of the CIE was to develop a repeatable system of color communication standards for manufacturers of paints, inks, dyes, and other colorants. These standards' most important function was to provide a universal framework for color matching. The Standard Observer and XYZ color space were the foundations of this framework; however, the unbalanced nature of the XYZ space—as demonstrated by the xyY chromaticity diagram—made these standards difficult to clearly address.

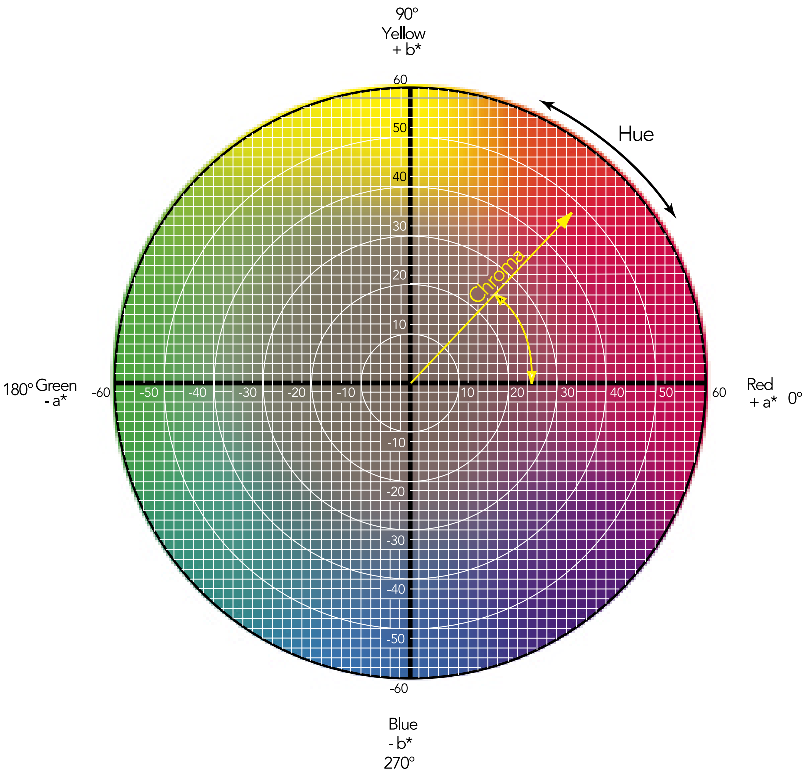


As a result, the CIE developed more uniform color scales called *CIE L*a*b** and *CIE L*u*v**. Of these two models, CIE L*a*b* is the most widely used. The well-balanced structure of the L*a*b* color space is based on the theory that a color cannot be both green and red at the same time, nor blue and yellow at the same time. As a result, single values can be used to describe the red/green and the yellow/blue attributes. When a color is expressed in CIE L*a*b*, L* defines lightness; a* denotes the red/green value; and b* the yellow/blue value. In many ways, this color space resembles three-dimensional color spaces like HSL.

CIE L*C*H°

The L*a*b* color model uses rectangular coordinates based on the perpendicular yellow-blue and green-red axes. The *CIE L*C*H°* color model uses the same XYZ-derived color space as L*a*b*, but instead uses cylindrical coordinates of *Lightness*, *Chroma*, and *Hue* angle. These dimensions are similar to the Hue, Saturation (Chroma), and Lightness. Both L*a*b* and L*C*H° attributes can be derived from a measured color's spectral data via direct conversion from XYZ values, or directly from colorimetric XYZ values. When a set of numerical values are applied to each dimension, we can pinpoint the color's specific location in the L*a*b* color space. The diagram below shows the L*a*b* and L*C*H° coordinates graphed atop the L*a*b* color space. We'll revisit these color spaces later when we examine color tolerancing and verification.

These three-dimensional spaces provide a logical framework within which the relationship between two or more colors can be calculated. The "distance" between two colors in these spaces identifies their "closeness" to each other.



As you will recall, the viewer's gamut is not the only element of color that changes with every different viewing situation. *Lighting conditions* also influence the appearance of colors. When describing a color using tristimulus data, we must also describe the reflectance data of the light source. But which light source do we use? Again, the CIE has stepped in to establish *standard illuminants*, as well.

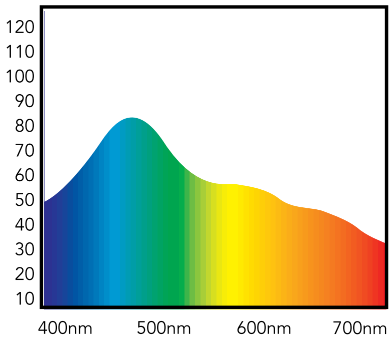
CIE Standard Illuminants

Defining the properties of the illuminant is an important part of describing color in many applications. The CIE's standards provide a universal system of pre-defined spectral data for several commonly-used *illuminant* types.

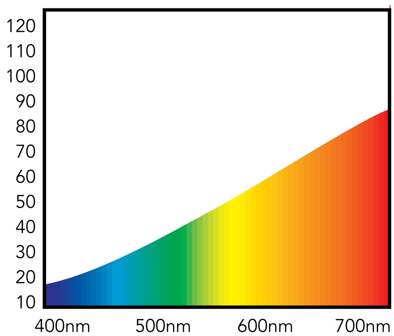
The CIE standard illuminants were first established in 1931 as a set of three, identified as A, B, and C:

- **Illuminant A** represents incandescent lighting conditions with a color temperature of about 2856° K;
- **Illuminant B** represents direct sunlight at about 4874° K; and
- **Illuminant C** represents indirect sunlight at about 6774° K.

Later, the CIE added a series of D illuminants, a hypothetical E illuminant, and a series of F illuminants. The D illuminants represent different daylight conditions, as measured by color temperature. Two such illuminants—D_{50} and D_{65}—are commonly used as the standard illuminants for graphic arts viewing booths ("50" and "65" refer to color temperatures 5000° K and 6500° K, respectively).



"Bluish" daylight reflectance



"Warm" incandescent reflectance

These illuminants are represented in color calculations as spectral data. The spectral reflectance power of light sources—which are *emissive* objects—is really no different than the spectral data of a reflective colored object. You can recognize the influence of certain colors in different types of light sources by examining their relative power distribution as spectral curves.

Tristimulus color descriptions rely heavily on CIE standard color systems and illuminants. Spectral color descriptions, on the other hand, do not directly require this additional information. However, CIE standards do play an important role in the conversion of color information from tristimulus to spectral data. Next, let's explore further by examining the relationship between spectral data and tristimulus data.

SPECTRAL DATA VS. TRISTIMULUS DATA

We have examined the principle methods for describing color. These methods can be separated into two distinct categories:

- There is **spectral data**, which actually describes the surface properties of the colored object by demonstrating how the surface affects (reflects, transmits, or emits) light. Conditions such as lighting changes, the uniqueness of each human viewer, and different rendering methods have no effect on these surface properties.
- And, there is **tristimulus data**, which simply describes how the color of the object appears to a viewer or sensor, or how the color would be reproduced on a device such as a monitor or printer, in terms of three coordinates or values. CIE systems such as XYZ and L*a*b* locate a color in a color space using three-dimensional coordinates; while color reproduction systems such as RGB and CMY(+K) describe a color in terms of three values that can are mixed to generate the color.

As a color specification and communication format, spectral data has some distinct advantages over conventional tristimulus formats such as RGB and CMY(+K) values. Most importantly, spectral data is the only true description of the actual colored object. RGB and CMYK color descriptions, on the other hand, are dependent upon viewing conditions—on the type of device that is rendering the color; and on the type of lighting under which the color is viewed.

Device-Dependence

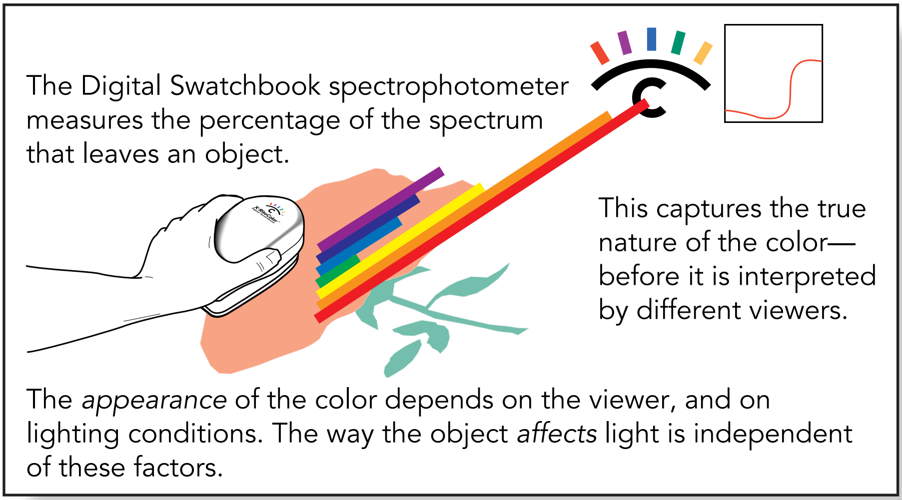
As we discovered in our color space comparison, every color monitor has its own range (or gamut) of colors that it can generate using its RGB phosphors—even monitors made in the same year by the same manufacturer. The same goes for printers and their CMYK colorants, which in general have a more limited gamut than most monitors.

To precisely specify a color using RGB or CMYK values, you must also define the characteristics of the specific device where you intend the color to appear.

Illuminant-Dependence

As we discussed earlier, different illuminants such as incandescent light and daylight have their own spectral characteristics. A color's appearance is greatly affected by these characteristics—the same object will often appear differently under different types of lighting.

To precisely specify a color using tristimulus values, you must also define the characteristics of the illuminant under which you intend the color to appear.



Device- and Illuminant-*Independence*

Measured *spectral* data, on the other hand, is both device- and illuminant-*independent*:

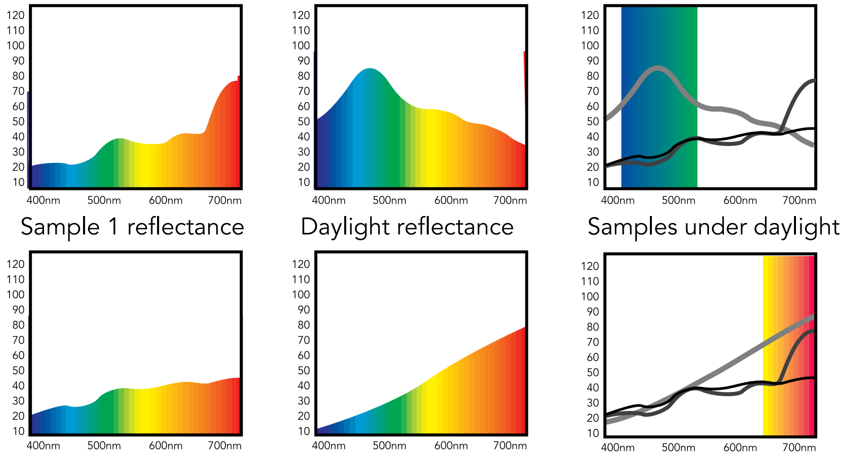
- Spectral data measures the composition of light reflected from an object *before* it is interpreted by a viewer or device.

- Different light sources appear differently when they are reflected from an object because they contain different amounts of the spectrum at each wavelength. However, the object always absorbs and reflects the same *percentage* of each wavelength, regardless of amount. Spectral data is a measurement of this *percentage*.

So, the two components of color that change with every viewing condition—the light source and the viewer or device—are "bypassed," and the ever-stable properties of the object surface are measured, instead. To accurately specify color, spectral data is all we need—it is, in short, "the real thing." On the other hand, RGB and CMYK descriptions are subject to "interpretation" by different viewers and devices.

Detecting Metamerism

Another advantage of spectral data is its ability to predict the effects of different light sources on an object's appearance. As we discussed earlier, different light sources



Sample 1 reflectance — Daylight reflectance — Samples under daylight

Sample 2 reflectance — Incandescent reflectance — Samples under incandescent

have their own compositions of wavelengths, which in turn are affected by the object in different ways. For example, have you ever matched a pair of socks and pants under fluorescent department store lighting, then later discover that they do not match as well under your home's incandescent lighting? This phenomenon is called *metamerism*.

The following example compares two shades of gray that are a metameric match. Under daylight conditions, these grays appear to match quite well. However, under incandescent lighting, the first gray sample takes on a reddish cast. These changes can be demonstrated by plotting the spectral curves for the different grays and the different illuminants, then comparing where their strongest reflectance power occurs in relation to each other and to the visible spectrum wavelengths:

When our samples are illuminated by daylight, the relationship between these two colors is enhanced in the blue region (the highlighted area), where the curves are close together. Incandescent light, on the other hand, distributes more reflectance power in the red region, where the two sample curves happen to separate sharply. So, under cooler lighting the differences between the two samples are not so apparent; but the differences are quite apparent when viewed in warmer lighting. Our eyesight can be fooled by these changes in lighting conditions. Because tristimulus data is illuminant-dependent, these formats cannot demonstrate the effects of these changes. Only spectral data can clearly detect these characteristics.

2 Color Measurement and Control

Now that we've learned the fundamentals of color and the different ways we can communicate color data, let's look at the ways we can *collect* this data. We've already touched on two instruments that measure color—*spectrophotometers* and *colorimeters*. First, we'll take a more detailed look at these instruments, along with a third commonly used graphic arts instrument, the *densitometer*. Then, we'll take a look at different types of color measurements and how they are used during specific phases of the digital imaging and graphic arts production workflow.

INSTRUMENTATION

We have discussed many scales for communicating and describing color—either by its primary color attributes, its perceptual attributes, or its actual spectral data. These models provide us with units of measurement similar to "inches" and "ounces." All we need is a set of "rulers" that can measure a color in terms of numeric expressions such as CIE L*a*b*. Today, the most commonly used instruments for measuring color are *densitometers*, *colorimeters*, and *spectrophotometers*.

Gathering Color Measurements

Color measurement instruments "receive" color the same way our eyes receive color: by gathering and filtering the manipulated wavelengths of light that are reflected from an object. Earlier, we demonstrated how this combination of light, object (in our case, a rose), and viewer caused us to perceive a "red" rose. When an instrument is the viewer, it "perceives" the reflected wavelengths as a numeric value. The scope and accuracy of these values depend on the measuring instrument—they can be interpreted as a simple *density* value by a densitometer; a *tristimulus* value by a colorimeter; or as *spectral data* by a spectrophotometer.

Assigning Numeric Values to Colors

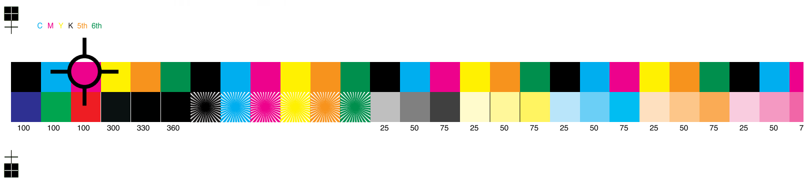
Each type of color measurement instrument does something that our eye cannot do: assign a specific value to the color that can be consistently analyzed in terms of numeric tolerances and control limits. Each instrument makes this conversion differently.

- Of these instruments, a **densitometer** is the most commonly used. A densitometer is a photo-electric device that simply measures and computes how much of a known amount of light is reflected from—or transmitted through—an object. It is a simple instrument used primarily in printing, pre-press, and photographic applications to determine the strength of a measured color.

Auto Tracking Densitometer (ATD)

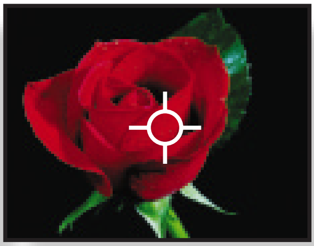
361T Transmission Densitometer

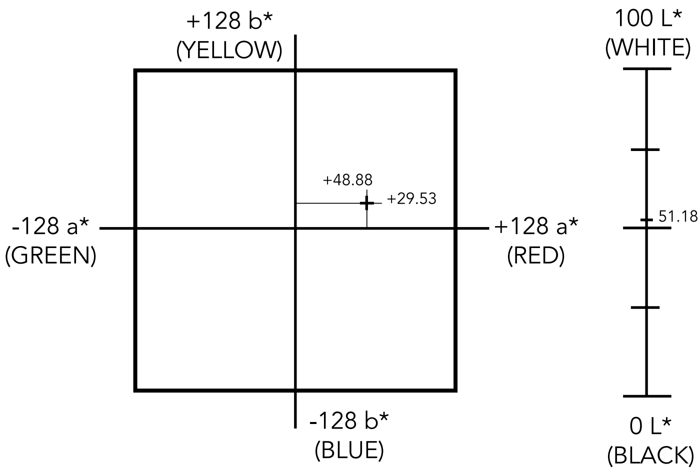
Densitometers such as X-Rite's ATD (above) and 361TR (left) simply measure the amount of light reflected from or transmitted through the object to determine its density or "strength."



In our example, the solid magenta patch on the measured color bar has a density of* D 1.17*. This value helps the press operator make necessary adjustments to process ink keys.

- A **colorimeter** also measures light, but it instead breaks the light down into its RGB components (in a manner similar to that of the human eye, a monitor, or a scanner). A color's numeric value is then determined using the CIE XYZ color space or one of its derivatives, such as CIE L*a*b* or CIE L*u*v*. These measurements are visually interpreted in a color space graph.



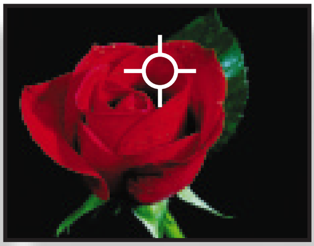


Colorimeters such as X-Rite's model 528 measure the amount of red, green, and blue light reflected from the object. Using CIE XYZ as the reference color space, this colorimetric data is converted into L*a*b* coordinates. In our example, the measured CIE L*a*b* value is "pinpointed" as:

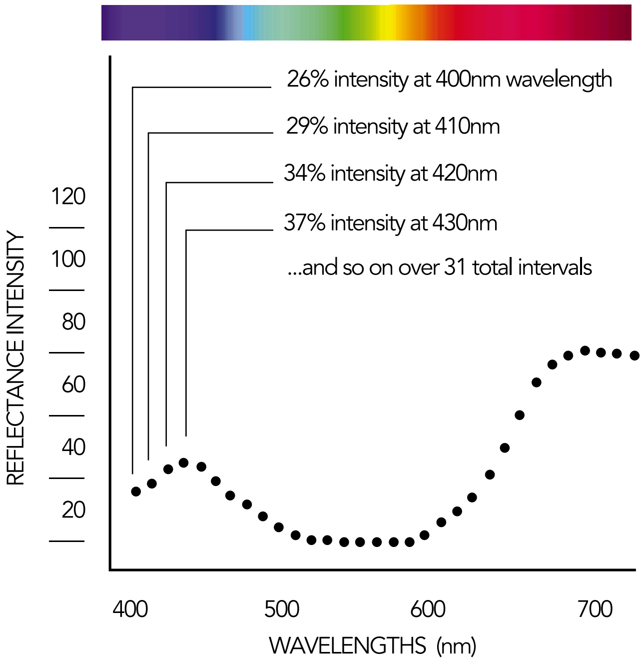
L* 51.13
a* +48.88
b* +29.53

(2° Standard Observer and Illuminant D_{50})

- A **spectrophotometer** measures spectral data—the amount of light energy reflected from an object at several intervals along the visible spectrum. These measurements result in a complex data set of reflectance values which are visually interpreted in the form of a spectral curve.



Spectrophotometers such as X-Rite's Digital Swatchbook build a spectral "fingerprint" by examining how a measured surface affects light at different wavelengths.



Because a spectrophotometer gathers such complete color information, this information can be translated into colorimetric or densitometric data with just a few calculations. In short, a spectrophotometer is the most accurate, useful, and flexible instrument available.

MEASUREMENT APPLICATIONS IN THE GRAPHIC ARTS WORKFLOW

Different types of color measurement instruments are used in various stages of the graphic arts production workflow. A precise measurement program can ensure consistent color results from initial ideas to the final printed piece—and all the exchanges from device-to-device in between. Different types of measurement are appropriate for specific production stages. For example, spectral data is the best measurement format for pinpoint color specifications; while simple density measurements are more appropriate for monitoring press sheet color bars over the course of a four-color process press run.

First, we should re-emphasize this important point: the typical RGB color space is much smaller than the range of colors that is visible to the human eye; and the CMYK printing process can achieve an even smaller gamut. Also, lighting conditions and materials such as colorants and substrates place additional limits on the gamut of reproducible color. Scanning and display technology continues to improve color bit depth and push the capabilities of RGB outward; and new printing technologies such as HiFi color have widened the process printing gamut. However, variations will always exist between original natural colors, their reproduction via scanners and monitor display, and their reproduction via different printing processes.

Color measurement allows us to achieve the best possible color production results:

- Minimal color variation between devices and production stages;
- these variations are predictable, and overall outputs are consistent; and
- any problematic color variations are quickly identified and corrected with little waste of time or materials.

Next, we'll discuss how specific types of color measurements can be applied to optimize color consistency and quality in some key stages of the production workflow:

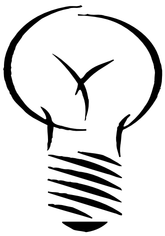
- Specification (by client and content creator)
- Color Management (by content creator and service provider)
- Formulation (by ink supplier and printer)
- Control (by printer)
- Verification (by printer, client, and content creator)

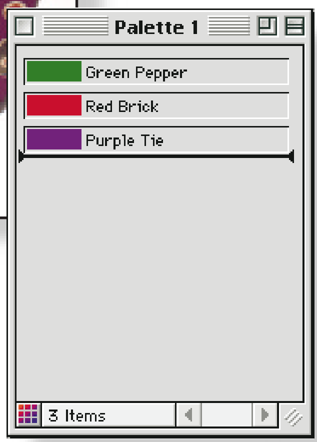
Note that this workflow is a full circle—the key is to present a finished product that matches the client's original color specifications as closely as possible.

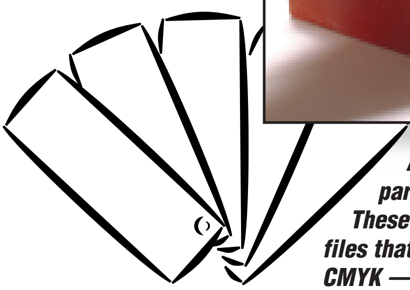
COLOR SPECIFICATION

The most complete way to define a color is with spectral data. Now that technological advances have made spectrophotometers widely available, spectral data is the logical best solution for describing, specifying, or identifying colors. Spectral measurements are especially crucial for colors outside the traditional CMYK color description—such as out-of-gamut spot colors and HiFi process colors. Spectral descriptions remain the same at any workflow stage because they are device-independent. In addition, RGB, CMYK, and custom ink formulations can be accurately derived from spectral data.

X-Rite's DIGITAL SWATCHBOOK system allows you to "point and click" its hand-held spectrophotometer on a color sample, then instantly view the color on your computer monitor. The measured color's *spectral* data is stored as a digital color. A collection of measured colors can be saved in a "palette," which can then be imported into other graphics programs such as Adobe Illustrator™. These palettes are also accessible from Photoshop™ via the Apple Color Picker. Beginning the color production work-flow with spectral descriptions means this precise, device-independent data can be utilized at other phases in the process—at your service provider, by your client, and by your printer.



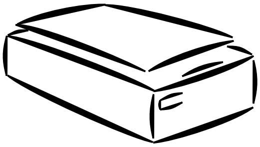


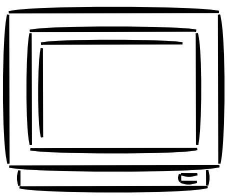


Any real-life color can become part of ColorShop's digital "palette." These palettes can be saved as EPS files that contain spectral data — RGB or CMYK — for each of their stored colors.

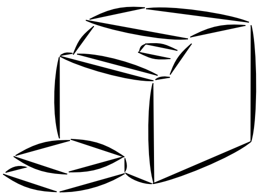
COLOR MANAGEMENT

Earlier we noted that there are as many RGB color spaces as there are monitors, and as many CMYK color spaces as there are printers. This situation creates a great deal of ambiguity and guesswork for designers who create and proof colors on their desktop devices. Scanned colors don't look the same when they are displayed on a monitor; on-screen colors do not match the printed proof; and the colors in image files display and output differently at each production site (design studio, service bureau, printer). *Color management systems (CMS)* help solve these problems at the desktop level, and in turn provide solutions "downstream," as well.





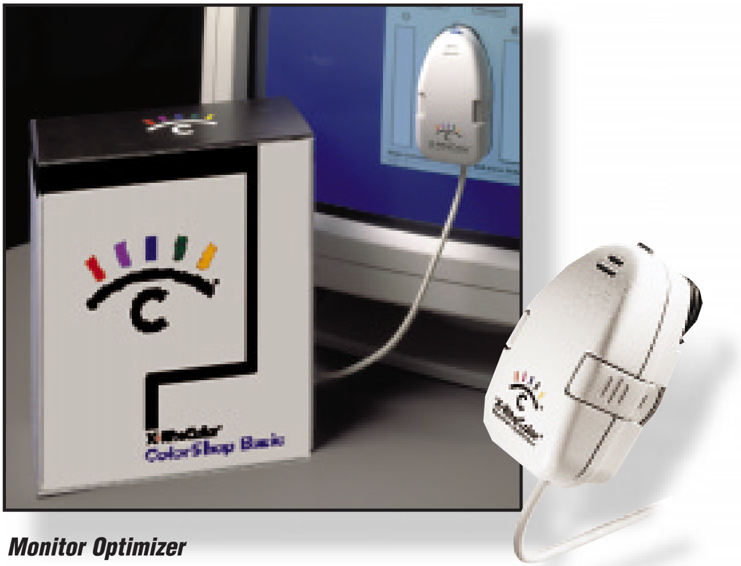
A color management system identifies the RGB and CMYK color spaces that are crucial to *your* work—those belonging to your scanner, monitor, and printer. Descriptions of these devices are appropriately named *profiles*, or also referred to as *characterizations*. Macintosh and Mac OS- compatible computers provide a built-in framework—called *Apple ColorSync*—for implementing and handling these device profiles. Color measurement instruments are used in conjunction with the CMS and CMS-supported software to gather the important performance data that comprises the device profiles, and to periodically monitor and adjust the performance of the devices. Utilizing your CMS, CMS-compatible software utilities and Plug-Ins, and color measurement instrumentation, you can achieve desktop color consistency in two major steps—device *calibration* and device *characterization*.



Device Calibration

Device calibration is the first step in the desktop color management process. Your monitor and output device performance capabilities can change over time—phosphor instability is a principle cause of monitor drift; and changes in colorants and room humidity can throw printer performance off course. Monitor and printer calibration procedures utilize different types of devices.

Monitor calibration is most accurately achieved using a colorimeter—such as X-Rite's Monitor Optimizer or model DTP92—and compatible calibration software. For example, the Monitor Optimizer sensor attaches directly to your monitor, positioned over a color target displayed on screen by the ColorShop Monitor Calibrator control panel. The target area flashes a series of colors, the instrument measures each patch; then the software collects the measurement data. This data is



Monitor Optimizer

analyzed to determine where any performance drift has occurred. Your monitor's gamma, white and black point, and color balance are adjusted and corrected accordingly. Finally, the software saves a monitor profile in the ColorSync Profiles folder in your system folder.

In addition to calibration, you can do some other things to ensure reliable monitor viewing: choose a neutral gray pattern for your on-screen "desktop;" avoid locating brightly-colored artwork adjacent to your monitor; avoid locating your workstation near windows or room lighting that is glaring or that changes frequently; and even shield your monitor on top and at the sides with a cardboard "awning". You can set your brightness and contrast knobs at the desired levels before calibration.

Output device calibration is typically achieved using a densitometer (or, increasingly using a colorimeter or spectrophotometer) and accompanying software. Calibration adjusts a device's output to correlate with the values requested by the software. In the case of a color printer, calibration ensures that the correct levels of cyan, magenta, yellow, and black colorants are printed. A typical test image features rows of patches—one row for each color the device can print. Each row's patches represent different percentages, usually arranged in 5% or 10% increments from solid to zero coverage. In the case of film imagesetters, on the other hand, output values are verified for a single separation film's tone values.

X-Rite DTP32 densitometer

These patches are measured to calculate the device's *linearity*—its ability to properly image the percentages assigned from the calibration software. An auto-scanning densitometer such as X-Rite's model DTP32 makes these measurements fast and easy by automatically scanning an entire row with one pass through the reading slot. The resulting measurements are communicated back to the software, where internal adjustments are made to the PostScript commands that control the color values sent to the output device.

Device Characterization / Profiling

Device characterization is the second step in the color management process, following device calibration. Characterization is the process of actually creating device profiles for your scanner, monitor, and printer. While many device manufacturers ship factory-generated, generic profiles on disk with their products, *custom* profiles that you create for your specific devices are more accurate and reliable, and therefore will yield better color results.

Scanner characterization involves using a scanned test print or transparency such as an IT8 Target, and then running a scanner characterization utility program. The IT8 test pattern consists of dozens of different color patches that represent a uniform sampling of the CIE XYZ or L*a*b* color space. The target comes with a data file containing the XYZ values for each patch. The utility compares these

IT8 Target for reflection scanners

known values to the scanner's device-dependent RGB representation of each color. Any differences between the two values are calculated. From this data, the scanner's color space can be determined. This unique color space information is saved as part of your scanner's custom profile.

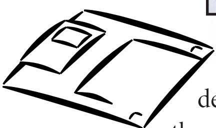
Monitor characterization is accomplished using the same instrumentation (such as Monitor Optimizer) and on-screen target sequence that is used for calibration. For characterization, the colorimetric data from the device is compared to the monitor's ability to render these colors, so the software can calculate how the monitor's color space relates to the XYZ color space. This unique information is the central component of the monitor's custom profile.

Printer characterization is similar to scanner characterization in that it measures a test pattern to determine the device's range of achievable colors. For printers, the test pattern is a uniform sampling of overprinted CMYK tints that are imaged using the output device.

Software for printer characterization uses a test image with 500 or more colored patches. This image is output to the printer. The patches are then measured, and the resulting colorimetric data is calculated into color space information for that specific printer, as it relates to the CIE XYZ or CIELAB color space. This information becomes the central component in the printer's custom profile.

Because characterization is concerned with the printer's ability to render a range of different process colors—not specific colorant densities—a colorimeter or spectrophotometer must be used to gather the measurements (X-Rite's Digital Swatchbook spectrophotometer, or DTP41 Auto Scan Spectrophotometer, for example).

X-Rite DTP41 Auto Scan Spectrophotometer

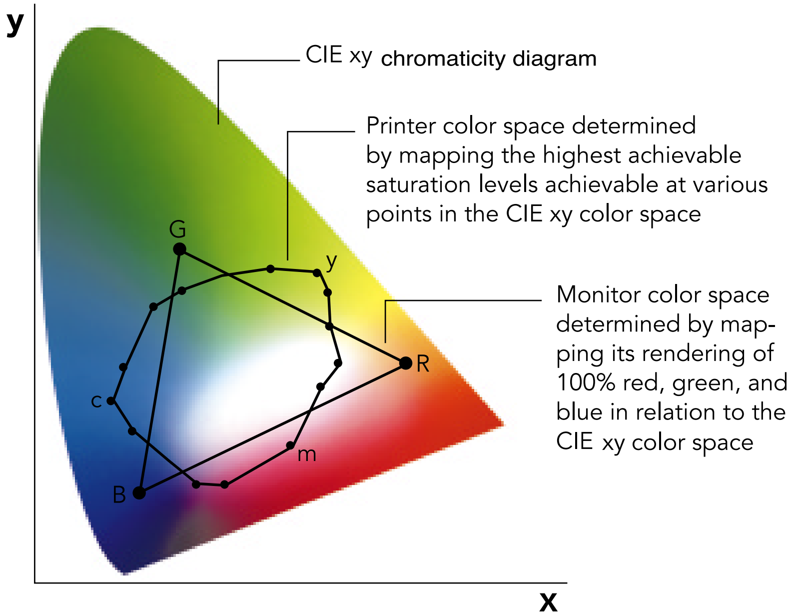


Proofing system and press characterizations can help clients and designers accurately predict the way colors will reproduce at later stages of the production process. Service bureaus and printers who utilize color measurement and management systems can consider supplying clients with custom profiles of their output devices. Knowing the capabilities of all the output devices in the workflow can further enhance your ability to make important color control decisions during the desktop design stage of production. Achieving color control early in the process can save review cycle time and wasted materials downstream.

Anatomy of A Device Color Space

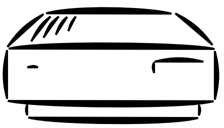
A device color space is "constructed" based on its ability to scan, display, or render different points in the CIE xy chromaticity chart. Most target patches represent various *hues* at maximum *saturation*—the first two color space dimensions (recall our discussion of hue, saturation, and lightness in the previous chapter). Various tints of black and the primary colors are also included to determine the device's capabilities for rendering different levels of *lightness*, as well.

The characterization software "knows" the device-independent values of the target's patches, which represent a device gamut. These known color values are compared to the device's actual, measured performance. The amount of difference at each point is determined, and the measured points are "mapped" in relation to the known points. The resulting information provides the characterization software with a detailed description of the device's unique capabilities.



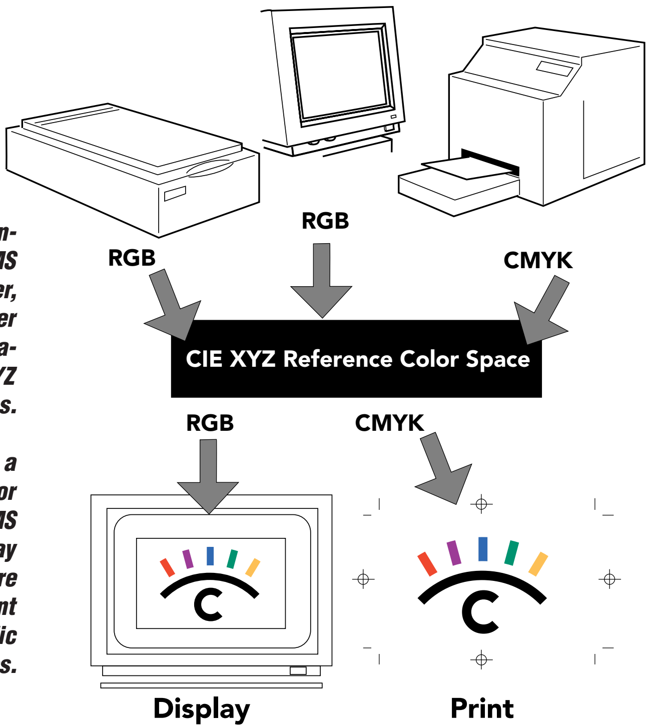
Profile-generating systems store device profiles in a specific location in your operating system software. Programs that utilize device profiles—such as the ColorShop software, Adobe® Illustrator™, Adobe® PageMaker™, Adobe® FreeHand™,Adobe® PhotoShop™, QuarkXPress® — allow you to activate the desired device profiles from the storage location via menus within the program's operating environment.

How Color Management Systems Works



The diagram on the previous page showing smaller RGB and CMYK color spaces "mapped" inside the xy gamut demonstrates the process of *gamut compression*. This process happens frequently when we move colors through the production process: our original scene contains colors that are not captured on photographic film; some colors in the photograph are not within the scanner's color space, or *gamut*; and still more colors are lost or replaced when the scan is displayed in a monitor's gamut. By the time our image is printed on proofing devices and on press, its original gamut has been compressed considerably. At each stage, out-of-gamut colors are replaced with the nearest approximate achievable colors.

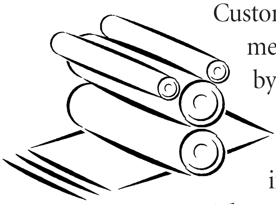
For example, Apple ColorSync helps you keep gamut compression predictable and under control. It utilizes your peripherals' profile information to calculate a "common ground" color space within the framework of CIE XYZ. When you use your profiled peripherals in conjunction with ColorSync, you work only with colors that are in the device color space areas that "overlap." Within this area, color space information can be easily translated from one device color space to the next. For example, you can more accurately predict your output colors based on what you see on your monitor.



This diagram demonstrates how a CMS converts scanner, monitor, and printer color space information into CIE XYZ coordinates.

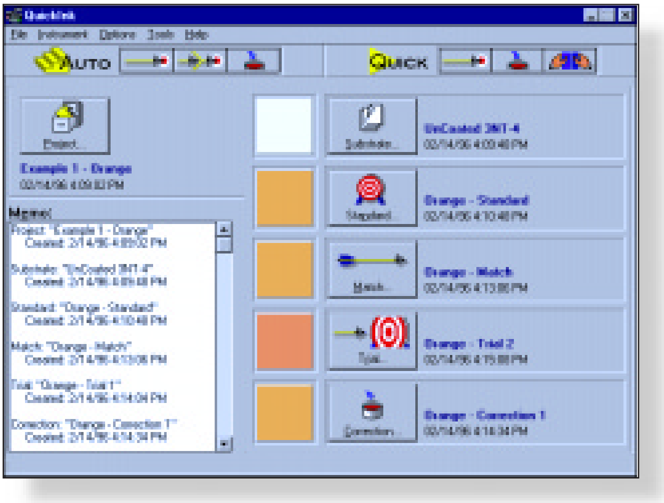
Using CIE XYZ as a universal color "language," the CMS calculates display RGB values that more accurately represent your printer's specific output capabilities.

COLOR FORMULATION



Custom formulation for special spot colors is based on spectrophotometric measurements of various ink and paper combinations. This is typically done by the ink manufacturer. Now, technological advances in measurement instrumentation and software have brought ink formulation to the printing site, where the actual production paper can be calculated into a custom ink formula that will match the customer's specifications. These affordable solutions, such as X-Rite's QuickInk system, utilize supplied spectral data, specification from existing color guides, or measurement of the actual sample or swatch.

QuickInk software formulates custom inks to match measured color data



COLOR CONTROL

Color control—or *process control*—is critical to achieving consistent, quality color throughout an entire print job, across different shifts, between printing press operators, or between batches of materials. In any printing or imaging application, color can vary on a single printed page, and from one page to the next. Measurement information can be used to control these color variations.

For example, densitometers are used to read *color bars*, which are basically small versions of test forms that are printed in unused areas of the printed page. Generally, color bars provide sample patches (of solid inks, tints, overprints, and special patterns) to test critical print characteristics. Calculations such as density, dot area, dot gain, print contrast, and apparent trap allow press operators to troubleshoot on-press color problems. Comparing color bar measurements between printed sheets clearly identifies any changes in printing characteristics.

These densitometric measurements indicate how the press is performing at that time. By comparing measurements of several press sheet color bars at various intervals during the press run, the press operator can:

- monitor overall press performance over time;
- monitor the performance of the individual ink keys over time; and
- document print quality for clients.

Measurements are analyzed in relation to control limits that have been established for the press. Any measurement data that is not within acceptable range of the control limits indicates a possible problem with the process or equipment. Having this information close at hand allows operators to quickly pinpoint problem areas and make fast, seamless adjustments to press settings with minimal waste of materials.

X-Rite's Auto Tracking Spectrophotometer (ATS) System automatically measures press sheet color bars at various intervals throughout the press run.

Measurement data is displayed on a nearby computer in the accompanying ATS software interface.

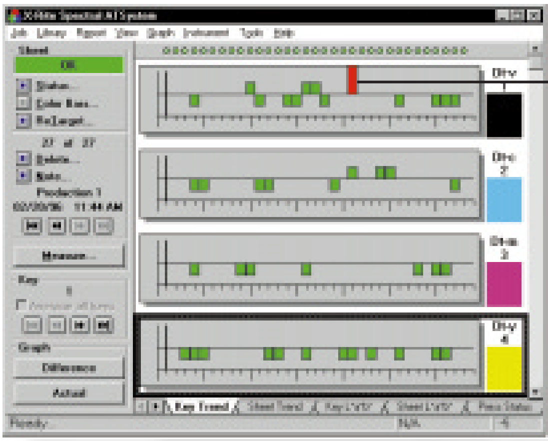
Today's newest printing technologies such as HiFi color can often be monitored and controlled more effectively with colorimetric or spectral measurement. HiFi printing applications that use CMYK+RGB, or custom touch-plate or bump colors are especially well-suited to process control using these tools, such as X-Rite's model 938 hand-held spectrophotometer, or the ATS System. As the achievable gamut of HiFi color printing expands, spectral data will play an increasing role in controlling HiFi's expanded palette of achievable process colors.

Control Limits

As we mentioned earlier, any press run will vary in its color output from sheet-to-sheet, from start to finish. Some variation is normal and acceptable. Control limits are established to ensure that the press run's variation *remains* normal and acceptable. They are similar to the lines on either side of a street lane—some variation within the lines is acceptable, as drivers typically make subtle steering adjustments. Problems can occur, however, if the vehicle—or the press' performance—suddenly veers beyond the lines.

Control limits are most commonly monitored using frequent densitometric measurements taken from press sheet color bars. For example, the Auto Tracking Spectrophotometer system features an accompanying software package that displays the measurement data in graphical formats showing press performance trends over time. These linear graphs quickly identify any ink density measurements that are much stronger or weaker than acceptable.

These graphs in the ATS software represent multiple color bar measurements over time. The horizontal center line of each graph is the optimal density value, and the lines above and below the center line are the acceptable limits for density variation.



Any measurements outside the control limits—especially a trend of these measurements—alerts the press operator to make adjustments to press settings.

COLOR VERIFICATION

Another key benefit of color measurement is the ability to monitor color accuracy at each step of the reproduction workflow, and ultimately verify that customer specifications have been achieved as closely as possible.

Verifying that the actual ink colors are correct—especially non-process ink colors—requires the capabilities of a colorimeter or spectrophotometer (a densitometer can also be used on these special colors, but typically only to measure strength). Because spectrophotometers can function as densitometers and colorimeters, they are the most logical and versatile method for controlling and verifying the quality of color reproduction.

Color Tolerances

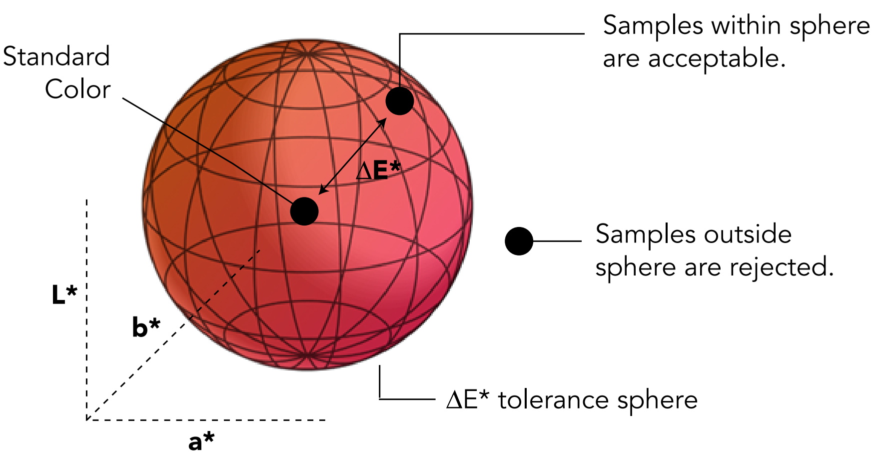
Verification between color specifications and actual color results is achieved by using tolerances that are based on numeric color measurement data. Color tolerancing involves comparing the measurements of several color samples (the color output) to the data of a known color *standard* (the specification or input). Then, the "closeness" of the samples to the standard is determined. If a sample's measured data is not close enough to the desired standard values, it is unacceptable and adjustments to the process or equipment may be required.

(While control limits and color tolerances are separate considerations, the product-tion workflow and print job should be set up with both parameters in mind. In general, a project should never have customer specifications that cannot be achieved within the printer's control limits.)

The amount of "closeness" between two colors can be calculated using a variety of color tolerancing methods. These methods calculate the "distance" between two sets of measurement coordinates within a three-dimensional color space such as L*a*b*. The most common methods are CIELAB and CMC.

CIELAB Tolerancing Method

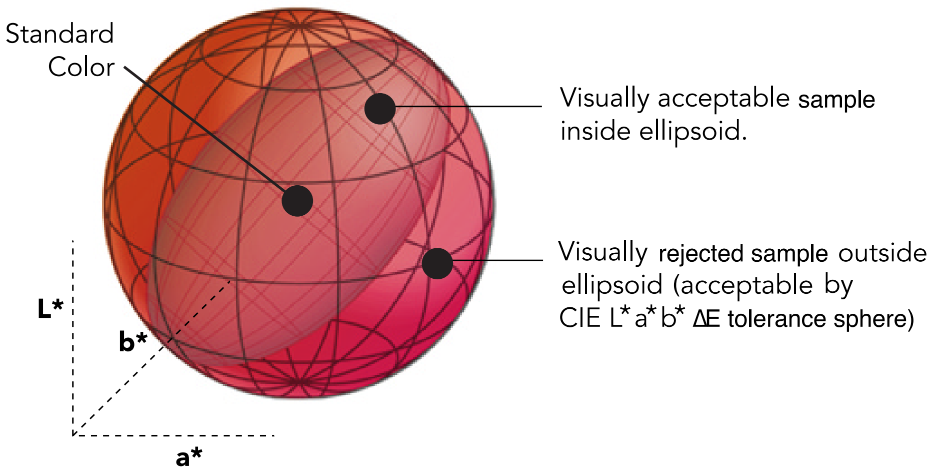
CIE LAB calculations are based on the L*a*b* color space we examined earlier. Using CIELAB, the standard color—or original specification—is pinpointed by its measure-ment data in the L*a*b* color space. Then, a theoretical "tolerance sphere" is plotted around the color. This sphere represents the acceptable amount of difference between the standard and other measured samples (the color output). Data that falls within the tolerance sphere represents an acceptable color. Measurements that fall outside the tolerance sphere are unacceptable.



The size of the tolerance sphere is determined by customer's specifications for acceptable color difference, which is expressed in delta (Δ) units such as ΔE (delta error). A typical customer tolerance in the graphic arts industry usually lies between 2 and 6 ΔE. This means, for example, that samples outside the tolerance box lie more than 6 Δ units away from the standard. Tolerances of less than 2 Δ units are typically unachievable given normal process variation, while a high tolerance could result in visible mismatches between specifications and results (highly dependent on the image). Differences between colors in an image that are within 4 Δ units of each other often are not visible to most viewers.

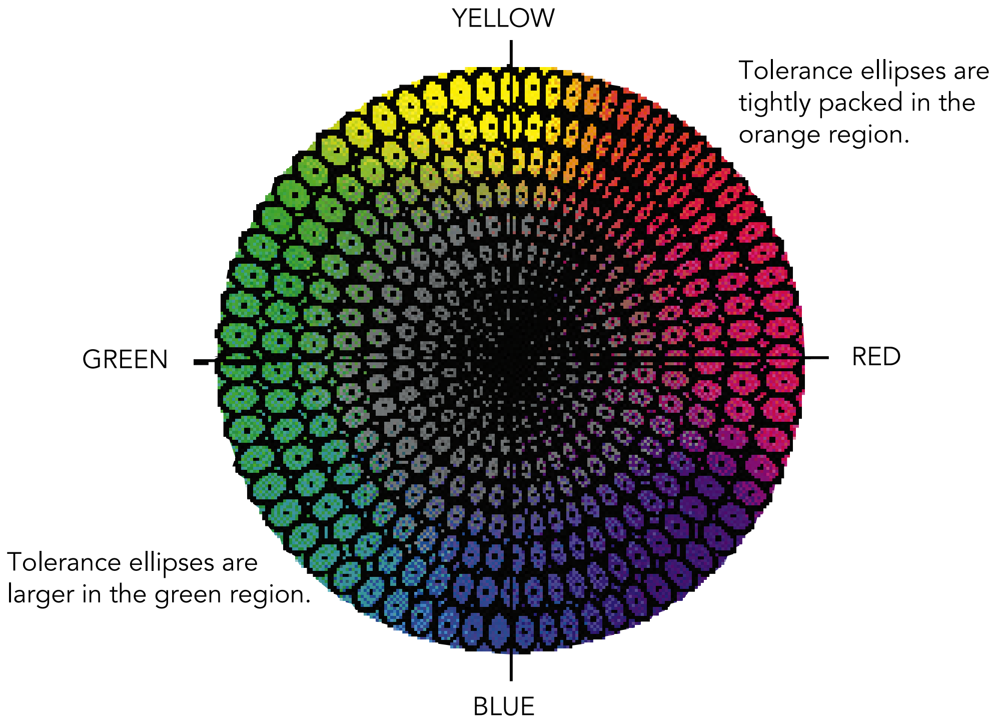
Elliptical Tolerancing Methods

Our eyes accept color matches inside elliptical regions, as opposed to the "spherical" regions used in the CIELAB tolerancing method. For this reason, the CIELAB method can often provide misleading results. For example, an "acceptable" color that falls within a CIELAB tolerance might actually lie outside the elliptical region of acceptability.



The CMC and CIE94 tolerancing methods directly addresses our "elliptical" perception of color difference, and therefore is regarded in many industries as a more logical and accurate tolerancing system than CIELAB. A similar color difference calculation called CIE94 is growing in popularity and also uses ellipsoids.

CMC and CIE94 are not new color spaces—they are simply tolerancing systems that are based on the L*a*b* color space. The calculations mathematically define an ellipsoid around a standard color in the color space. This ellipsoid consists of a semi-axis that corresponds to the attributes of hue, chroma, and lightness. It represents the area of acceptance in relation to the standard, the same way the CIELAB "sphere" defines acceptable difference limits. In CMC and CIE94, the size of the ellipsoid varies depending on its position in the color space—for example, in the orange region, ellipsoids are narrower, while in the green region, ellipsoids are wider. Also, ellipsoids in high-chroma regions are



larger than those in low-chroma regions.

SUMMARY

This Color Guide has introduced you to the subjects of color communication, measurement, and control in a format that we hope has been clear and interesting. Behind each concept and process we briefly covered in this book, there is much additional information and technical data that can be added to your knowledge of color production. However, the information you have learned in this booklet will help you get started in the world of color measurement and control, by providing a basic explanation of color science and theory, the different tools used to measure color, and the different stages of the production process where color measurement is important. With this knowledge in hand, we recommend that you continue your studies by reading the excellent literature listed in our bibliography inside the back cover.

The key point we want you to remember is this: If you can *measure* color, you can *control* color. Without measurement, describing and verifying color can be ambiguous and unreliable. With numerical measurement data, however, colors can be described and verified with precision and confidence.

3 Glossary

A

Absorb/Absorption: Dissipation of the energy of electromagnetic waves into other forms as a result of its interaction with matter; a decrease in directional transmittance of incident radiation, resulting in a modification or conversion of the absorbed energy.

Additive Primaries: Red, green, and blue light.

When all three additive primaries are combined at 100% intensity, white light is produced. When these three are combined at varying intensities, a gamut of different colors is produced. Combining two primaries at 100% produces a subtractive primary, either cyan, magenta, or yellow:

100% red + 100% green = yellow; 100% red + 100% blue = magenta;
100% green + 100% blue = cyan

See *Subtractive Primaries.*

Appearance: Manifestation of the nature of objects and materials through visual attributes such as size, shape, color, texture, glossiness, transparency, opacity, etc.

Attribute: Distinguishing characteristic of a sensation, perception or mode of appearance. Colors are often described by their attributes of hue, saturation or chroma, and lightness.

B

Black: The absence of all reflected light; the color that is produced when an object absorbs all wavelengths from the light source.

When 100% cyan, magenta, and yellow colorants are combined, the resulting color-theoretically-is black. In real-world applications, this combination produces a muddy gray or brown. In four-color process printing, black is one of the process inks.

The letter “K” is used to represent Black in the CMYK acronym to avoid confusion with Blue’s “B” in RGB.

Brightness: The attribute of visual perception in accordance with which an area appears to emit or reflect more or less light (this attribute of color is used in the color model HSB—Hue, Saturation, Brightness). See *Lightness.*

C

Calibration: To check, adjust, or systematically standardize the graduations of a device.

Chroma: The attribute of visual perception in accordance with which an area appears saturated with a particular color or hue-for example, a red apple is high in chroma; pastel colors are low in chroma; black, white, and gray have no chroma (this attribute of color is used in the color model L*C*H—Lightness, Chroma, Hue). Also referred to as *Saturation.*

Chromaticity, Chromaticity Coordinates: Dimensions of a color stimulus expressed in terms of hue and saturation, or redness-greenness and yellowness-blueness, excluding the luminous intensity. Generally expressed as a point in a plane of constant luminance. See *CIE xy Chromaticity Diagram*.

CIE (Commission Internationale de l'Eclairage): A French name that translates to International Commission on Illumination, the main international organization concerned with color and color measurement.

CIE94: The CIE94 tolerancing method utilizes three-dimensional ellipsoids as "containers" for color acceptance. CIE94 is conceptually similar to CMC2:1 but lacks some of the hue and lightness adjustments. It is expected that CIE94 will evolve over the next few years as additional studies are performed.

CIELAB (or CIE L*a*b*, CIE Lab): Color space in which values L*, a*, and b* are plotted at right angles to one another to form a three-dimensional coordinate system. Equal distances in the space approximately represent equal color differences. Value L* represents Lightness; value a* represents the Redness/Greenness axis; and value b* represents the yellowness/blueness axis. CIELAB is a popular color space for use in measuring reflective and transmissive objects.

CIE Standard Illuminants: Known spectral data established by the CIE for four different types of light sources. When using tristimulus data to describe a color, the illuminant must also be defined. These standard illuminants are used in place of actual measurements of the light source.

CIE Standard Observer: A hypothetical observer having the tristimulus color-mixture data recommended in 1931 by the CIE for a 2° viewing angle. A supplementary observer for a larger angle of 10° was adopted in 1964. If not specified, the 2° Standard Observer should be assumed. If the field of view is larger than 4°, the 10° Standard Observer should be used.

CIE xy Chromaticity Diagram: A two-dimensional graph of the chromaticity coordinates, x as the abscissa and y as the ordinate, which shows the spectrum locus (chromaticity coordinates of monochromatic light, 380-770nm). It has many useful properties for comparing colors of both luminous and non-luminous materials.

CIE Tristimulus Values: Amounts of the three components necessary in a three-color additive mixture required for matching a color: in the CIE System, they are designated as X, Y, and Z. The illuminant and standard observer color matching functions used must be designated; if they are not, the assumption is made that the values are for the 1931 CIE 2° Standard Observer and Illuminant C.

CIE Chromaticity Coordinates: x and y values that specify the location of a color within the CIE chromaticity diagram.

CMC (Color Measurement Committee): Of the Society of Dyes and Colourists in Great Britain. Developed a more logical, ellipse-based equation for computing ΔE values as an alternative to the spherical regions of the CIELAB color space.

CMY: The subtractive primaries cyan, magenta, and yellow. See *Subtractive Primaries*.

Color Management: Matching colors between an original image, scanner, monitor, color printer and final press sheet.

Color Matching Functions: Relative amounts of three additive primaries required to match each wavelength of light. The term is generally used to refer to the CIE Standard Observer color matching functions designated. See *CIE Standard Observer*.

Color Model: A color measurement scale or system that numerically specifies the perceived attributes of color. Used in computer graphics applications and by color measurement instruments.

Color Separation: The conversion of the red, green, and blue color information used in a computer into cyan, magenta, yellow, and black channels that are used to make printing plates.

Color Space: A three-dimensional geometric representation of the colors that can be seen and/or generated using a certain color model.

Color Specification: Tristimulus values, chromaticity coordinates and luminance value, or other color-scale values, used to designate a color numerically in a specified color system.

Color Temperature: A measurement of the color of light radiated by an object while it is being heated. This measurement is expressed in terms of absolute scale, or degrees Kelvin. Lower Kelvin temperatures such as 2400°K are red; higher temperatures such as 9300°K are blue. Neutral temperature is gray, at 6504°K.

Color Wheel: The visible spectrum's continuum of colors arranged into a circle, where complementary colors such as red and green are located directly across from each other.

Colorants: Materials used to create colors–dyes, pigments, toners, phosphors.

ColorSync: Built-in color management architecture for Apple Macintosh computers. Third-party vendors utilize the ColorSync framework to provide device calibration, device characterization, and device profile-building methods.

Colorimeter: An optical measurement instrument that responds to color in a manner similar to the human eye–by filtering reflected light into its dominant regions of red, green, and blue.

Colorimetric: Of or relating to values giving the amounts of three colored lights or receptors–red, green, and blue.

Contrast: The level of variation between light and dark areas in an image.

Control Limits: The amount of acceptable variation in press capabilities over the course of a press run.

Cyan: One of the process ink colors for printing. Pure cyan is the "redless" color; it absorbs all red wavelengths of light and reflects all blue and green wavelengths.

D

D_{50}: The CIE Standard Illuminant that represents a color temperature of 5000°K. This is the color temperature that is most widely used in graphic arts industry viewing booths. See *Illuminants D*.

D_{65}: The CIE Standard Illuminant that represents a color temperature of 6504°K.

Delta (Δ): A symbol used to indicate deviation or difference.

Delta Error (ΔE): In color tolerancing, the symbol ΔE is used to express Delta Error, the total color difference computed using a color difference equation.

The color difference is generally calculated as the square root of the combined squares of the chromaticity differences, Δa^* and Δb^*, and the Lightness difference, ΔL. See *CIE94.*

Densitometer: A sensitive, photoelectric instrument that measures the density of images or colors.

Density: The ability of a material to absorb light–the darker it is, the higher the density.

Device-Dependent: Describes a color space that can be defined only by using information on the color-rendering capabilities of a specific device. For example, the RGB color space must be generated by a monitor, a device which has specific capabilities and limitations for achieving its gamut of colors. In addition, all monitors have different capabilities and limitations, as do different scanners, printers, and printing presses.

Device-Independent: Describes a color space that can be defined using the full gamut of human vision, as defined by a standard observer, independent of the color-rendering capabilities of any specific device.

Device Profile: Device-specific color information that is a characterization of a device's color rendering and reproduction capabilities. Monitor profiles, scanner profiles, and printer profiles are utilized in a color management system such as Apple ColorSync to help the devices communicate color information with each other. Profiles are created by calibration and/or characterization method.

Dye: A soluble colorant; as opposed to pigment, which is insoluble.

Dynamic Range: An instruments range of measurable values, form the lowest amount it can detect to the highest amount it can handle.

E

Electromagnetic Spectrum: The massive band of electromagnetic waves that pass through the air in different sizes, as measured by wavelength. Different wavelengths have different properties, but most are invisible–and some completely undetectable–to human beings. Only wavelengths that are between 380 and 720 nanometers in size are visible, producing light. Invisible waves outside the visible spectrum include gamma rays x-rays, microwaves and radio waves.

Emissive Object: An object that emits light. Usually some sort of chemical reaction, such as the burning gasses of the sun or the heated filament of a light bulb.

F

Fluorescent Lamp: A glass tube filled with mercury gas and coated on its inner surface with phosphors. When the gas is charged with an electrical current, radiation is produced which in turn energizes the phosphors, causing the phosphors to glow.

Four-Color Process: Depositing combinations of the subtractive primaries cyan, magenta, yellow, and black on paper to achieve . These colorants are deposited as dots of different sizes, shapes, and angles to create the illusion of different colors. See *CMY, Subtractive Primaries.*

G

Gamut: The range of different colors that can be interpreted by a color model or generated by a specific device.

Gamut Compression: Or tonal range compression. The color space coordinates of a color space with a larger gamut are reduced to accommodate the smaller gamut of a destination color space. For example, the gamut of photographic film is compressed for representation in the smaller CMYK gamut used for four-color process printing. See *Gamut.*

Gamut Mapping: Converting the coordinates of two or more color spaces into a common color space. Often results in tonal range compression. See *Gamut Compression.*

H - I

HiFi Printing: Process printing that expands the conventional four-color process gamut using additional, special ink colors.

Hue: The basic color of an object, such as "red," "green," "purple," etc. Defined by its angular position in a cylindrical color space, or on a Color Wheel.

ICC (International Color Consortium): A group of hardware and software companies dedicated to the development of a specification that is OS independent and provides the digital imaging, printing and related industries with a data format for defining the color and reproduction characteristics of devices and their related media.

Illuminant: Incident luminous energy specified by its spectral distribution.

Illuminant A (CIE): CIE Standard Illuminant for incandescent illumination, yellow-orange in color, with a correlated color temperature of 2856°K.

Illuminant C (CIE): CIE Standard Illuminant for tungsten illumination that simulates average daylight, bluish in color, with a correlated color temperature of 6774°K.

Illuminants D (CIE): CIE Standard Illuminants for daylight, based on actual spectral measurements of daylight. D65 with a correlated color temperature of 6504°K is most commonly used. Others include D50, D55, and D75.

Illuminants F (CIE): CIE Standard Illuminant for fluorescent illumination. F2 represents a cool white fluorescent lamp (4200 K), F7 represents a broad-band daylight fluorescent lamp (6500 K), and F11 represents a narrow-band white flourescent lamp (4000 K).

Intensity: Saturation or reflective energy as related to visible wavelengths of light. Reflectance of wavelengths at high intensity generates high saturation, or chroma.

IT8: Series of test targets and tools for color characterization established by ANSI (American National Standards Institute) Committee IT8 for Digital Data Exchange Standards. Different IT8 targets are used to characterize different devices such as scanners and printers.

K - L

Kelvin (K): Unit of measurement for color temperature. The Kelvin scale starts from absolute zero, which is -273° Celsius.

L*C*H: A color space that is similar to CIELAB, except uses cylindrical coordinates of lightness, chroma, and hue angle instead of rectangular coordinates.

Light: Electromagnetic radiation in the spectral range detectable by the human eye (approx. 380 to 720nm).

Lightness: The attribute of visual perception in accordance with which an area appears to emit or reflect more or less light. Also refers to the perception by which white objects are distinguished from gray objects and light-from dark-colored objects.

M

Magenta: One of the process ink colors for printing. Pure magenta is the "greenless" color; it absorbs all wavelengths of green from light and reflects all red and blue wavelengths.

Metamerism, Metameric Pair: The phenomenon where two colors appear to match under on light source, yet do not match under a different light source. Two such colors are called a metameric pair.

Monitor RGB: Same as RGB; monitor RGB simply refers specifically to the color space that can be achieved by a particular monitor using combinations of red, green, and blue light.

Munsell Color Charts: A three-dimensional color system developed by Albert Munsell that is based on the attributes Munsell Hue, Munsell Value, and Munsell Chroma.

N - O - P

Nanometer (nm): Unit of length equal to 10^{-9} meter, or one millionth of a milli-meter. Wavelengths are measured in nanometers.

Overprint: On a press sheet color bar, overprints are color patches where two process inks have been printed, one atop the other. Checking the density of these patches allows press operators to determine trap value. The term Overprint also applies to any object printed on top of other colors.

Phosphors: Materials that emit light when irradiated by cathode rays, or when placed in an electric field. The quantity of visible light is proportional to the amount of excitation energy present.

Photoelectric: Pertaining to the electrical effects of light or other radiation–for example, emission of electrons.

Photoreceptor: The cone- and rod-shaped nuerons that cover the retina of the eye. Photoreceptors are excited by visible wavelengths, then send signals to the brain where the sensation of color is perceived.

Pigment: An insoluble colorant; as opposed to a dye, which is soluble.

Pixel: A tiny picture element that contains red, green, and blue information for color rendering on a monitor or a scanner. When generating colors, pixels are similar to dots of ink on paper. A monitor resolution description in terms of pixels-per-inch (ppi) is similar to a printer resolution description in terms of dots-per-inch (dpi).

Primary Colors: The dominant regions of the visible spectrum: red, green, and blue; and their opposite colors cyan, magenta, and yellow. See *Additive Primaries, Subtractive Primaries.*

Prism: Triangular-shaped glass or other transparent material. When light is passed through a prism, its wavelengths refract into a rainbow of colors. This demonstrates that light is composed of color, and indicates the arrangement of colors in the visible spectrum. See *Visible Spectrum.*

Process Control: Using densitometric and colorimetric measurement data from press sheet color bars to monitor press performance throughout the press run. Data is analyzed in relation to established control limits. See *Control Limits*

R

Reflective Object: A solid object that returns some or all of the wavelengths of light that strike its surface. A reflective object that returns 100% of all light is called a perfect diffuser-a perfectly white surface.

Reflectance: The percentage of light that is reflected from an object. Spectrophotometers measure an object's reflectance at various intervals along the visible spectrum to determine the object color's spectral curve. See *Spectral Curve, Spectral Data.*

RGB: The additive primaries red, green, and blue. See *Additive Primaries.*

S

Saturation: The attribute of color perception that expresses the amount of departure from the neutral gray of the same lightness. Also referred to as chroma.

Sequence: The order in which inks are deposited on paper by a printing press.

Spectral Curve: A color's "fingerprint"— a visual representation of a color's spectral data. A spectral curve is plotted on a grid comprised of a vertical axis-the level of reflectance intensity; and a horizontal axis-the visible spectrum of wavelengths. The percentage of reflected light is plotted at each interval, resulting in points that form a curve.

Spectral Data: The most precise description of the color of an object. An object's color appearance results from light being changed by an object and reflected to a viewer. Spectral data is a description of how the reflected light was changed. The percentage of reflected light is measured at several intervals across its spectrum of wavelengths. This information can be visually represented as a spectral curve.

Spectrophotometer: An instrument that measures the characteristics of light reflected from or transmitted through an object, which is interpreted as spectral data.

Spectrum: Spatial arrangement of electromagnetic energy in order of wavelength size. See *Electromagnetic Spectrum, Visible Spectrum*

Standard: An established, approved reference against which instrument measurements of samples are evaluated.

Subtractive Primaries: Cyan, Magenta, and Yellow. Theoretically, when all three subtractive primaries are combined at 100% on white paper, black is produced. When these three are combined at varying intensities, a gamut of different colors is produced. Combining two primaries at 100% produces an additive primary, either red, green, or blue:

100% cyan + 100% magenta = blue; 100% cyan + 100% yellow = green;
100% magenta + 100% yellow = red

T

Tolerance: The amount of acceptable difference between a known correct standard (usually the customer's specifications) and a set of measured samples. See *Delta Error*

Transmissive Object: An object that allows light to pass through from one side to the other. The color of a transmissive object results from the manipulation of wavelengths of light as they pass through.

Tristimulus: A method for communicating or generating a color using three stimuli–either additive or subtractive colorants (such as RGB or CMY), or three attributes (such as lightness, chroma, and hue).

Tristimulus Data: The three tristimulus values that combine to define or generate a specific color, such as R 255/G 255/B 0. Tristimulus data does not completely describe a color–the illuminant must also be defined. Also, in device-dependent color models such as RGB, the capabilities of the viewer or color-rendering device must also be defined. See *Device-Dependent.*

V - W - X - Y

Viewing Booth: A enclosed area with controlled lighting that is used in graphic arts studios, service bureaus, and printing companies as a stable environment for evaluating proofs and press sheets. Viewing booths are generally illuminated using graphic arts industry-standard D65 lighting, and are surfaced in neutral gray colors. See *D65.*

Visible Spectrum: The region of the electromagnetic spectrum between 380 and 720 nanometers. Wavelengths inside this span create the sensation of color when they are viewed by the human eye. The shorter wavelengths create the sensation of violets, purples, and blues; the longer wavelengths create the sensation of oranges and reds.

Wave: A physical activity that rises and then falls periodically as it travels through a medium.

Wavelength: Light is made up of electromagnetic waves; wavelength is the crest (peak)-to-crest distance between two adjacent waves.

White Light: Theoretically, light that emits all wavelengths of the visible spectrum at uniform intensity. In reality, most light sources cannot achieve such perfection.

Yellow: One of the process ink colors for printing. Pure yellow is the "blueless" color; it absorbs all wavelengths of blue from light and reflects all red and green wavelengths.

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