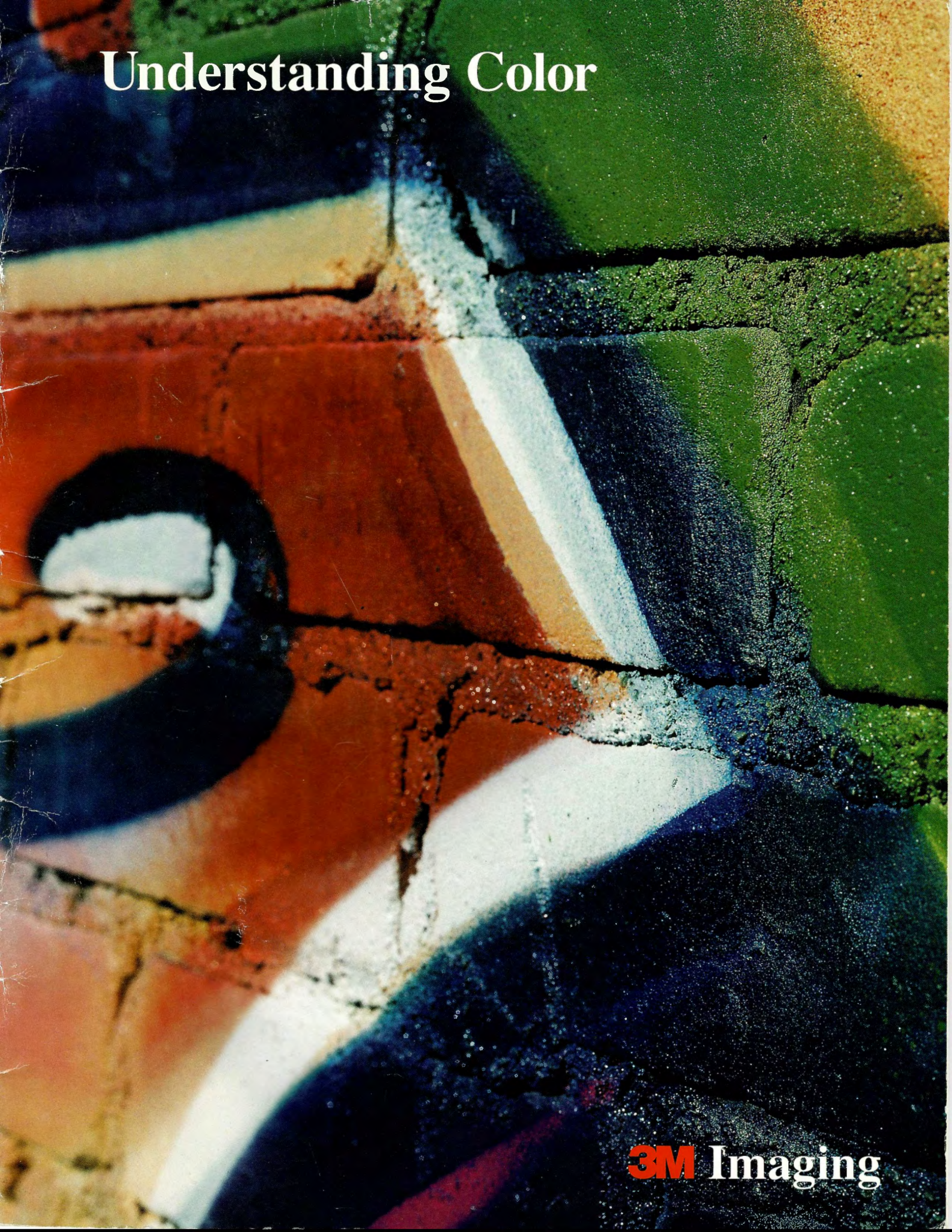
Understanding Color



3M Imaging

Graffiti, Inc. is a program created by the St. Paul, Minnesota Police Department and local citizens to combat the proliferation of graffiti in the city of St. Paul. The program seeks to document illegal graffiti art, identify the graffiti artists, and redirect their artistic energy by providing legal and safe environments to practice their art. Since the program's inception in Spring 1993, Graffiti, Inc. has organized more than ten commissioned projects around St. Paul including billboards, buses and murals. The cover photo, Knowledge is the Key, was commissioned by Dunn Brothers Coffee on Grand Avenue in St. Paul. As a result of the attention the mural received, twenty more young graffiti artists came forward to voluntarily participate in the Graffiti, Inc. program.

Understanding Color

Preface

Think about what color means to us in our day-to-day lives. Color adds excitement and interest to our sense of sight. We are delighted by the vibrant colors in a Matisse painting or the beauty of a forest in the fall. Color affects our emotions with hot reds, cool blues, soothing greens. Winter, with its relative absence of color, evokes coldness, a barren time while Spring, with its explosion of color, promises growth, beauty and renewal. By reproducing color in photography, paintings, printing or television, we bring excitement to that medium. But, what is color? How do we perceive it? How is it reproduced?

Color is a complex subject which can be studied in great depth. In fact, there are college degree programs available in color science. This book attempts to simplify the subject of color and provide an understanding of fundamental color principles.

Although the information in this book could be valuable for anyone who works with color, it is intended primarily for those in the graphic arts industry who must make informed judgements during the color reproduction process. Until recently, jobs in the graphic arts industry were highly specialized and color expertise was left to a small group of skilled tradespeople. As electronic publishing continues to evolve, more and more knowledge of color issues is required by all those involved in the reproduction process, from designers and art directors, to service bureau personnel, prepress personnel and press operators. Working with color can be tricky. A little color knowledge can prevent a lot of frustration — and expense.

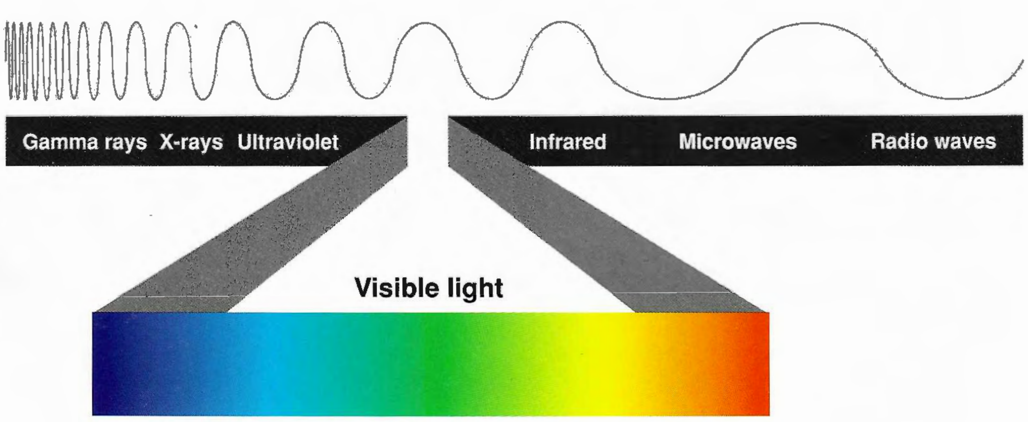
We at 3M hope this book will be useful in better understanding the fascinating and complex subject of color.

What is Color?

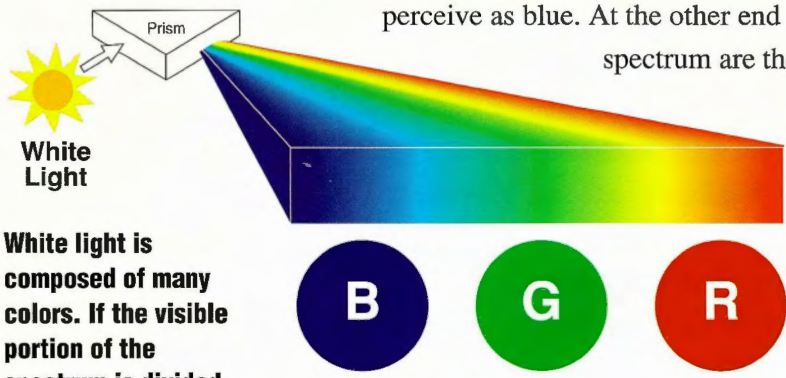
Imagine a world without color — for that is what really exists. All the objects that surround us have no color. Color exists only in our minds. Color is a visual sensation that involves three elements — a light source, an object and a viewer. Light from the sun or another light source strikes objects around us, is reflected and modified by the objects, then reaches the receptors in our eyes and is interpreted by our brains into something we call color. Since color only exists in our minds, explaining the physical aspects of color is just part of the story. The way objects appear to us and the judgements we make about color are determined by a combination of many factors. Some of these factors are easy to measure and some are not. Individual perceptual differences, eye fatigue and mood of the viewer are as important to a discussion about color as are the properties of light sources and objects. Color as perceived by the human eye cannot be simulated by any instrument, nor can it be reproduced by any printing process.

Light is essential for vision. Light causes color. Without light, color would not exist. Light that appears white to us, such as light from the sun, is actually composed of many colors. Each color has its own measurable wavelength or combination of wavelengths. (Light travels in waves much like waves produced by dropping a pebble in a pond, except light waves are extremely small.) The wavelengths of light are not colored, but produce the sensation of color. Light is a form of energy. All wavelengths of light are part of the electromagnetic energy spectrum. The spectrum is a continuous sequence of energy waves that vary in length from

Visible light is a very small portion of the electromagnetic energy spectrum. The spectrum is a continuous sequence of energy waves that vary in length with the shorter wavelengths at one end and longer wavelengths at the other.



short to long. Visible light — the wavelengths our eyes can detect — is a small portion of the entire spectrum. At one end of the visible spectrum are the short wavelengths of light we perceive as blue. At the other end of the visible spectrum are the longer wavelengths of light we perceive as red. All the other colors we can see in nature are found somewhere along the spectrum between blue and red. Beyond the limits at each end of the visible spectrum are the short wavelengths of ultraviolet light and X-rays and the long wavelengths of infrared radiation and radio waves which are not visible to the human eye.

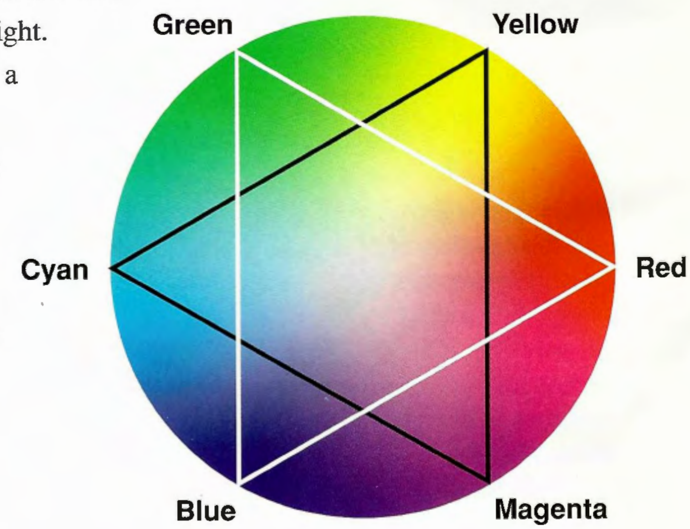


White light is composed of many colors. If the visible portion of the spectrum is divided into thirds, the predominant colors are blue, green and red.

We can separate a beam of white light into its component colors by passing it through a glass prism which causes the light beam to bend. Each wavelength, or color, bends at a slightly different angle which separates the white light into an array of colors. When the sun comes out after a rainstorm, water droplets in the air can act as prisms and display the arc of colors in the sky we see as a rainbow.

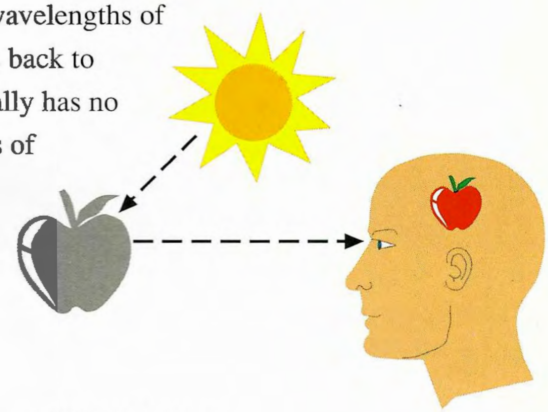
If the visible portion of the spectrum is divided into thirds, the predominant colors are blue, green and red. These are the primary colors of light. Visible colors can be arranged in a circle, commonly known as the color wheel. Blue, green and red form a triangle on the color wheel. In between the primary colors are the secondary colors, cyan, magenta and yellow which form another triangle.

Visible colors can be arranged in a circle, commonly known as the color wheel. The primary colors of light, red, green and blue (RGB), form a triangle on the color wheel. In between the primary colors are the secondary colors, cyan, magenta and yellow (CMY).



How is Color Perceived?

Objects in nature derive their color from colorants they possess that absorb or subtract certain wavelengths of light while reflecting other wavelengths back to the viewer. For example, a red apple really has no color, it merely reflects the wavelengths of white light that cause us to see red and absorbs most of the other wavelengths. The viewer (or detector) can be the human eye, film in a camera or a light-sensing instrument.



The human eye contains two basic types of light receptors, rods and cones. The rods are sensitive only to the presence of light, not color. The cones are sensitive to color. During normal daytime vision, it is the cones, not the rods, that actively contribute to vision. At night, the more sensitive rods take over and give us "night vision." There are three groups of cones, each sensitive to a portion of the visible color spectrum — red light, green light and blue light. The brain receives signals from the cones, processes them, then evokes the sensation of color. Various combinations of light waves evoke the sensation of other colors.

Color is a visual sensation that involves three elements — a light source, an object and a viewer.

A red apple really has no color. It merely reflects the wavelengths of white light that cause us to see red and absorbs most of the other wavelengths.

Color perception varies from person to person. Perception is a subjective phenomenon influenced by many variables including the light source, surrounding colors, mood of the viewer and individual variations in our visual systems. A small number of people have color-deficient vision. The most common form is the inability to distinguish between reds and greens. These people are considered color-blind. This phenomenon may result from one type of cone missing or a defect that affects analysis in the brain. Color blindness affects about 8% of men and less than 0.5% of women.

How is Color Reproduced?

Throughout history, reproducing the colors we see in nature has taken many forms. The media and methods used to reproduce color include color paintings, printing presses, color film, color monitors, color printers, etc. There are only two basic ways, however, of reproducing color — additive and subtractive.

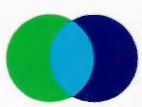
Additive Color System (RGB)

The additive color system involves light — light emitted directly from a source, before it is reflected by an object. Light of a specific color, or wavelength (for example, a theatrical spotlight), can be produced by directing white light through a special filter that allows the desired wavelength to pass and blocks others. The additive reproduction process mixes various amounts of red, green and blue light to produce other colors. Combining one of the additive primary colors with another produces the additive secondary colors cyan, magenta, yellow.

To illustrate this, imagine three spotlights, one red, one green and one blue focused from the back of an ice arena on skaters in an ice show. Where the blue and green spotlights overlap, the color cyan is produced; where the blue and red spotlights overlap, the color magenta is produced; where the red and green spotlights overlap the color yellow is produced. When added together, red, green and blue lights produce what we perceive as white light.

The Additive Color System (RGB):

- **Uses colored lights.**
- **Mixes different amounts of red (R), green (G) and blue (B) light to produce other colors.**
- **Begins with darkness. When combined in equal amounts, red, green and blue light produce white light.**

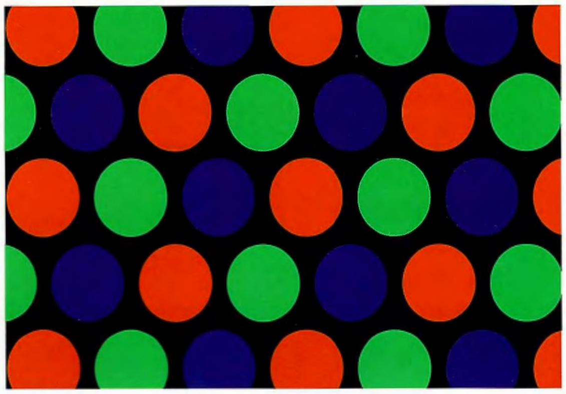


G + B light = CYAN

R + B light = MAGENTA

R + G light = YELLOW

R + G + B lights (in equal amounts) = WHITE



Television screens and computer monitors are examples of systems that use additive color. A mosaic of thousands of red, green and blue phosphor dots make up the images on video monitors. The phosphor dots emit light when activated electronically. It is the combination of different intensities of red, green and blue light that produces all the colors on a video monitor. Because the dots are so small and close together, we do not see them individually, but see the colors formed by the mixture of light. Colors often vary from one monitor to another. This is not new information to anyone who has visited an electronics store with various brands of televisions on display. Also, colors on monitors change over time. Currently, there are no color standards for the phosphors used in manufacturing monitors for the graphics arts industry.

Television screens and computer monitors are examples of the use of additive color. The combination of different intensities of light from red, green and blue phosphor dots produce all the colors on a monitor.

To summarize: Additive color involves the use of colored lights. It starts with darkness and mixes red, green and blue light together to produce other colors. When combined in equal amounts, the additive primary colors produce the appearance of white.

Subtractive Color System (CMY)

The subtractive color system involves colorants and reflected light. Subtractive color starts with an object (often a substrate such as paper or canvas) that reflects light and uses colorants (such as pigments or dyes) to subtract portions of the white light illuminating an object to produce other colors. If an object reflects all the white light back to the viewer, it appears white. If an object absorbs (subtracts) all the light illuminating it, no light is reflected back to the viewer and it appears black. It is the subtractive process that allows everyday objects around us to show color. Remember the example of the red apple? The apple really has no color. It has no light energy of its own. Colorants in the apple's skin absorb the green and blue wavelengths of white light and reflect the red wavelengths back to the viewer, which evokes the sensation of red.

Color paintings, color photography and all color printing processes use the subtractive process to reproduce color. In these cases, the reflective substrate is canvas (paintings) or paper (photographs, prints) which is usually white.

For example, printing presses use color inks that act as filters and subtract portions of the white light striking the image on paper to produce other colors. Printing inks are transparent which allows light to pass through to and reflect off of the paper base. It is the paper that reflects any unabsorbed light back to the viewer. The offset printing process uses cyan, magenta and yellow (CMY) process color inks and a fourth ink, black. The black printing ink is designated K to avoid confusion with B for blue. Overprinting one transparent printing ink with another produces the subtractive secondary colors, red, green, blue.

The Subtractive Color System (CMY):

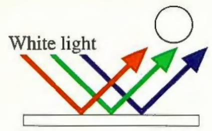
- **Uses colorants (pigments or dyes).**
- **Uses cyan (C), magenta (M) and yellow (Y) colorants to subtract portions of the white light illuminating an object to produce other colors.**
- **Begins with a white substrate (usually). When combined in equal amounts, cyan, magenta and yellow colorants produce the appearance of black.**

C + M + Y colorants (in equal amounts) = BLACK

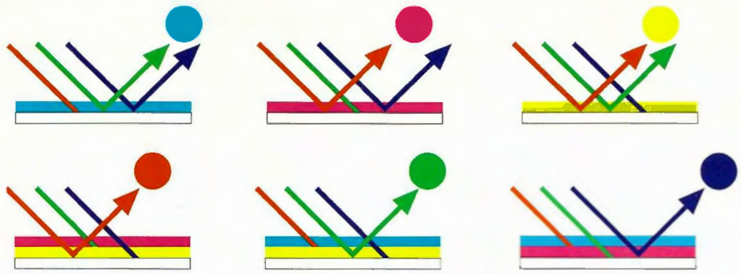
To be reproducible on press, an original color image, such as a photograph, must first be converted into a pattern of small dots for each of the four colors (CMYK). When printed with ink on paper, the small dots fool the eye and give the visual appearance of the original image.

The following is true for inks printed on a white substrate and illuminated with white light:

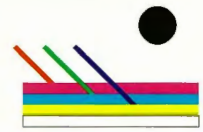
	Ink Color	Absorbs	Reflects	Appears
Single ink	C	Red light	Green and Blue light	Cyan
	M	Green light	Red and Blue light	Magenta
	Y	Blue light	Red and Green light	Yellow
Overprints	M + Y	Green and Blue light	Red light	Red
	C + Y	Red and Blue light	Green light	Green
	C + M	Red and Green light	Blue light	Blue
	C + M + Y	Red, Green, and Blue light	None	Black



An object appears white because all portions of white light illuminating it are reflected back to the viewer.



The illustrations above show process inks printed on white paper. Each process printing ink (cyan, magenta, yellow) absorbs or subtracts certain portions of white light and reflects other portions back to the viewer. Process printing inks are transparent. It is the paper that reflects unabsorbed light back to the viewer.

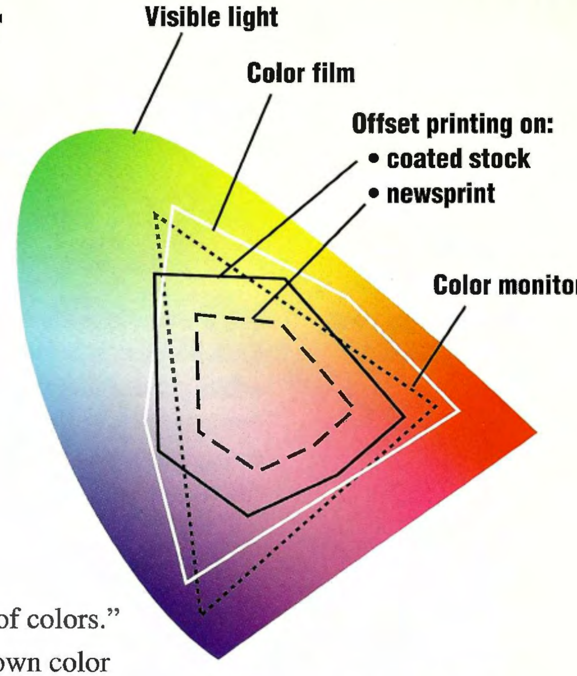


In theory, an overprint of all three process colors absorbs all portions of white light and produces the appearance of black. In reality, a muddy brown is produced. For this reason, black is used as a fourth printing ink.

In theory, a perfect process ink would absorb 100% of one primary color of light and allow reflection of 100% of the other two. If this were true, an overprint of all three process color inks would absorb all portions of the white light (red, green, blue), reflect no light back to the viewer and produce the appearance of black. In reality, printing inks contain impurities and no process ink is perfect. For example, even the best cyan ink does not absorb all the red light and does not reflect all the green and blue light. Therefore, when the three process inks are combined equally, a brown color is produced, not black. Black is used as a fourth printing ink to add depth to the shadow areas and enhance detail in the image overall.

To summarize: Subtractive color involves colorants and reflected light. It uses cyan, magenta and yellow pigments or dyes to subtract portions of white light illuminating an object to produce other colors. When combined in equal amounts, pure subtractive primary colors produce the appearance of black.

The Limitations of Color Reproduction



The colors we see in nature represent an extremely wide range of colors. When it comes to reproducing color, however, we run into limitations. No color reproduction system (color film, color monitors, printing presses, etc.) can reproduce the entire range of colors we see in nature.

Color Gamuts

Color gamut is another term for "range of colors." Each color reproduction system has its own color gamut. For example, the gamut of colors that can be reproduced on photographic film is greater than the gamut of colors that can be produced with process color inks on paper using the offset printing process. Computer screens display more — and different — colors than can be produced on color film or most color printing devices.

How many colors are there?

If you are a human eye - billions

If you are a computer screen - 16 million

If you are photographic film - 10 to 15 thousand

If you are a printing press - 5 to 6 thousand

Additive Color vs. Subtractive Color

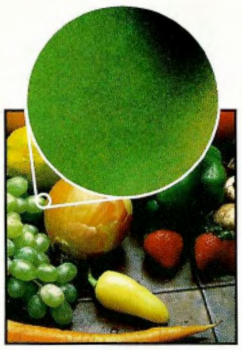
Video monitors use the additive color system. Offset printing uses the subtractive color system. Computer screens display a larger gamut of colors than can be produced on press and by most color printing devices. This is important to know when using the computer as a design tool. The color you see on your computer monitor is probably not what you will get when the job is printed.

What are Color Gamuts?

Each color reproduction system is capable of producing a certain range of colors, or color gamut. Color gamuts for different systems may overlap, but do not match. No printing device or color monitor can produce the range of colors our eyes can detect. This illustration shows color gamuts mapped for several color reproduction systems on a horseshoe-shaped slice of three-dimensional color space.

Because the printing process cannot reproduce the range of colors the eye can see, the colors in this illustration are approximate.

Continuous-Tone Image



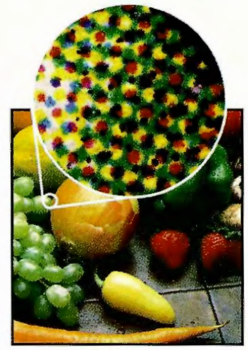
A continuous-tone image, such as a photograph, has a continuous range of density levels between the lighter (highlight) and darker (shadow) areas.

The limitations of the offset printing (subtractive) process are due in part to the image screening process and in part to the type of paper used to print the image. The screening process converts an original continuous-tone image, such as a color photograph, into a pattern of small dots for each process color so the image can be printed with a pigment (wax, toner, ink) or dye on paper. A continuous-tone image shows a continuous density range between lighter and darker areas. An ink-printable image (screened image) is made up of small dots which creates the illusion of lighter and darker tones. A screened image can be produced using a fixed grid pattern of different-sized dots, or by varying the number of randomly placed, same-size dots — or a combination of the two.

Screening Process and Tone Compression

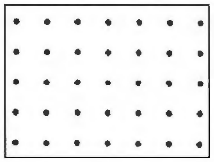
In offset printing, to be ink-printable, a continuous-tone image such as a photograph is converted into small dots of varying sizes using a camera and a halftone screen or, more commonly, a digital scanner. The original color image is separated into four separate halftone images — one for each of the three process colors and one for black. Historically, reproduction of continuous-tone images has relied on halftone screening methods that produce dots of different sizes in a fixed grid pattern. To be reproducible on press, each area of the original image is converted to a certain dot size to give the same visual appearance as the original image. When printed, areas with larger dots appear darker than areas with smaller dots. The size of each halftone dot is measured in terms of dot area percentage, from 1% to 100%. In a conventional halftone image, the dot size changes proportionately to the tonal value of the original image.

Halftone Image

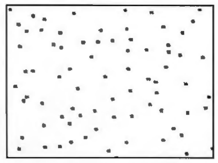


A halftone image is an ink-printable image made up of a pattern of different-sized dots. When we view a printed image from a distance, our eyes do not distinquish the small dots. Instead, we see the illusion of a continuous-tone image.

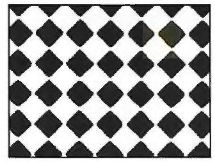
To be reproducible on press, an original color image, such as the one on the left, must first be separated into four individual screened images, as shown to the right — one for each of the three process colors (CMY) and one for black (K). When printed together, the four colors create the illusion of the original image.



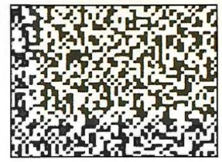
Conventional highlight dot area



Stochastic highlight dot area



Conventional midtone dot area



Stochastic midtone dot area

Conventional Halftone vs. Stochastic Screening

These illustrations show dots produced by two types of screening methods: conventional halftone screening and stochastic screening.

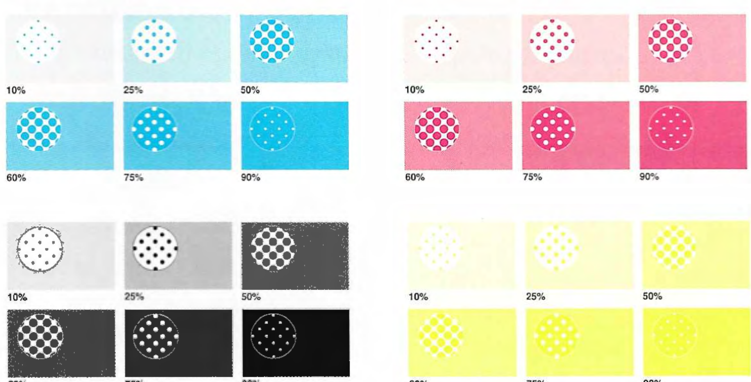
Conventional halftone screening methods produce dots of different sizes in a fixed grid pattern.

Stochastic screening produces very small, same-sized dots spaced randomly apart. Some stochastic systems randomly place variably-sized dots.

The coarseness of the grid, or screen ruling, determines the distance from the center of one dot to another. Newer digital screening methods produce very small, similar-sized dots randomly placed, not on a fixed grid. In these screened images, the number of small dots in a given area changes proportionately to the tonal value of the original image. Regardless of the screening method, a continuous-tone image must be converted into small dots to be reproducible on press.

The goal of four-color process printing is to create the illusion of continuous-tone color. Reproducing good tone is considered the first and foremost objective in achieving good color reproduction. The primary factor that limits color reproduction with subtractive color systems is tone compression.

What is tone? Tone is actually the lightness/darkness value of an image. The tonal range of an image is the transition from the highlight (or minimum density) to the shadow (or maximum density) areas. On a printed sheet, the highlight areas have minimum ink coverage and the shadow areas have maximum ink coverage.



Tone gradation for the four printing colors showing the appearance of different dot percentage areas. The halftone dot structure corresponding to each dot percentage is shown enlarged in the circles.

What is Tone?

Tone is actually the lightness/darkness value of an image. The tonal range of an image is the transition from the light areas to the dark areas.

In the conventional halftone process, each area of an original image is converted to a certain dot size to give the same visual appearance as the original image. When printed, areas with larger dots appear darker than areas with smaller dots. The size of each halftone dot is measured in terms of dot area percentage, from 1% to 100%.

The density range between the highlight and shadow areas can vary from one image to another. One image may have a narrow tonal range while another image can show a wide tonal range. Regardless of the tonal range, the number of density levels in a continuous-tone image far exceeds the number of density levels in a screened image. In other words, the number of density levels of an original is usually far greater than what is achievable on press. This means the tonal range of an original image must be compressed during the image reproduction process. The result is tone compression which requires that certain parts of the tonal range must be emphasized at the expense of others. Because of this inevitable compromise, a decision must be made as to what parts of an original image are the most important to reproduce accurately. The entire tonal range of an original image is usually difficult to reproduce on press. Detail in the highlight areas may have to be sacrificed to hold the detail in the shadow areas or vice versa.

Tone compression is more manageable if the original image is produced using special photographic techniques. An experienced photographer can adjust the lighting of a subject to change the contrast, or reduce the tonal range, of the original image to match the capabilities of the reproduction process. A low-contrast image requires less tone compression than a high contrast image and is easier to reproduce on press.

What is Tone Compression?

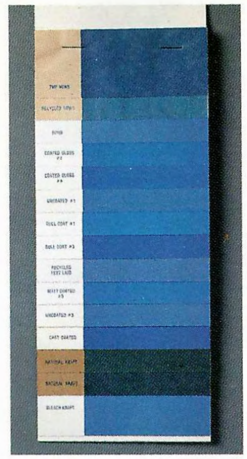
It is the reduction of the tonal range of an original continuous-tone image during the reproduction process. This occurs because the number of tones, or density levels, in an original image is far greater than what can be achieved on press and means certain tones must be emphasized at the expense of others.

Look closely at these two images, especially the dark areas (such as the rug) and the light areas (such as the white cushion). The image on the left was reproduced to hold detail in the shadow areas and resulted in loss of detail in the light areas. The image on the right was reproduced to hold detail in the high-light areas and resulted in loss of detail in the dark areas.

Husom & Rose Photographics

Paper Base

Another factor that affects the amount of colors reproducible by the subtractive process is the type of substrate — usually paper — used to print the image. As discussed earlier, offset printing uses transparent color inks that act as filters and subtract portions of the white light striking the image on paper to produce other colors. It is the paper that reflects any unabsorbed light back to the viewer. Paper stocks vary in color, gloss, brightness, texture and absorbency. A press that prints on coated paper produces a wider range of colors than a press that prints on uncoated paper. This is because the rougher surface of the uncoated paper scatters the light and reduces the amount of light reflected back to the viewer. Smooth, glossy white paper returns more light to the viewer. The range of colors on a substrate such as newsprint, which is usually rough, uncoated and yellowish, is more limited. A paper with a bluish cast will absorb some red and green wavelengths and cause colors to appear grayer than if printed on white paper. The effect of the paper base is so important to the appearance of a printed sheet that it can be considered a fifth color.



This shows the same ink printed on different papers. The effect of the paper base is so important to the appearance of a printed sheet that it can be considered a fifth color.(Courtesy of Cal-Ink.)

The Role of a Color Proof

Once a print job is on the press, changes are costly. The primary role of a color proof is to predict what a job will look like when printed. Using a color proof — and knowing what to look for in a proof — saves time and money by allowing changes to be made before a job goes on press. A proof serves as a communication and quality control tool at many steps in the production process. It is used within a production environment to monitor how a job is progressing. It is used with the customer to determine if color correction is necessary. It is used with the printer to check image quality and serve as a pressroom guide. A color proof often serves as a "contract" between the printer and the customer. This means the customer expects that the printed sheet will look like the proof. In the pressroom, the press operator makes adjustments to produce printed sheets that match the proof.

To be useful, a color proof must match the color, tonal range and visual appearance of the printing process. First, the colorants of the proofing system must simulate both the primary and secondary hues produced by the printing inks. Next, the proof must simulate the tone compression inherent in the printing process used. Finally, a proof must match the overall appearance of the printed sheet. Factors that affect overall appearance include the substrate, or paper stock, and gloss level.

A common pitfall is to judge a proof on how pleasing it is to the eye without considering how well it represents the printing process. If a proof cannot be matched on press, the proof creates frustrations for the press operator and unrealistic expectations for the customer.

The Importance of Viewing Conditions

The color of an object depends on the light source, the wavelengths of light the object reflects and the perception of the viewer. Different light sources affect what we see. You have probably experienced how colors appear to change when viewed under different lighting conditions. For example, the shirt you buy in a shop with fluorescent lighting can look different when viewed at home under incandescent light. The greenness of the fluorescent light in the shop and the redness of the incandescent light at home cause the same object to reflect different amounts of light back to the viewer, and therefore cause the sensation of a different color.

If an apple appears red when illuminated with white light, it means the apple is absorbing the green and blue wavelengths of white light and reflecting the red wavelengths back to the viewer. If the same apple is illuminated with light minus the red wavelengths, it would appear black. This is because all the wavelengths of light illuminating the apple would be absorbed and none would be reflected back to the viewer.

Accurate visual evaluation is an essential part of any successful print job. The eye, no matter how well trained, can be overwhelmed by the many variables, including viewing conditions, that contribute to the color of an image. Because of these variables, standards have been established for different industries to aid in color evaluation. For the printing industry, American National Standards (ANS) and the International Standards Organization (ISO) have specified that standard viewing conditions for color evaluations and comparisons are a 5000 Kelvin light source and a neutral gray surround. A 5000 Kelvin light source — designated as D50 by some lamp manufacturers — emulates daylight and provides a balanced output of red, green and blue light.

Use standard viewing conditions to maintain quality at each step of the color reproduction process. For the printing industry, standard viewing conditions for color evaluations and comparisons are a 5000 Kelvin light source and a neutral gray surround.

Viewing colors on a video monitor is subject to many variables including temperature, surrounding colors and room lighting. Viewing standards do not currently exist for color monitors.

When evaluating color, such as a color proof or press sheet, be sure to use a viewing booth with standard lighting conditions whenever possible. Also, our eyes can fatigue after looking at an image for a long time. When you are evaluating or comparing color images, give yourself a break and come back with "fresh" eyes to make final color decisions.

Why and How is Color Measured?

Color measurement is an important part of any quality production system. The fact that color can be measured gives us the means to control color during the image reproduction process.

Why can't we rely on our eyes to evaluate color? One reason is that color perception is influenced by many variables including eye fatigue, individual perception differences and viewing conditions. Color perception varies from person to person. Also, our ability to remember color is poor and our color vocabulary is rather inadequate. For example, if a group of people were asked to think of a color such as red, it is likely each person would have a different red in mind. If a group were presented with a hundred different reds from which to choose and asked to pick out the red that matches something they have seen countless times, such as the 3M logo, it is likely each person would pick out a different red. Show a red apple to a group of people, and it is likely each person would use different terms to describe the color of the apple.

If we cannot rely on our eyes to measure color or determine color differences, how do we define, measure and control color? Although we cannot measure how our brains interpret color, we can measure the physical properties that cause the sensation.

The Three Dimensions of Color

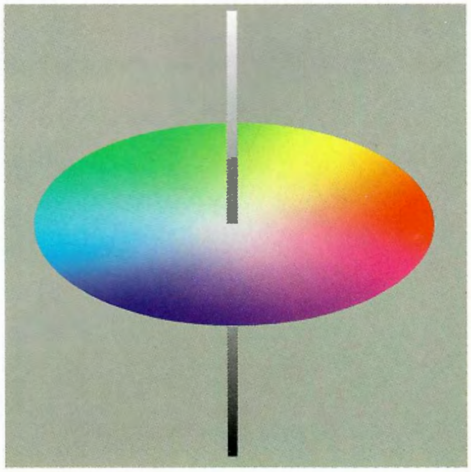
How is color measured? Although individuals perceive color differently, there are three general characteristics of color perception that everyone uses. Color can be plotted according to these characteristics. First, we can identify the basic color group, such as red, orange, yellow, etc. This is called HUE. Also, we can generally identify the intensity, vividness or saturation of a color. This is called CHROMA. Lastly, we can tell if a color is light or dark. This is called LIGHTNESS. All colors can be located in a three-dimensional model of color space (a 3D map of visible color) with hue, chroma and lightness as the three dimensions. With these three values, we can describe and measure color precisely.

The three dimensions of color:

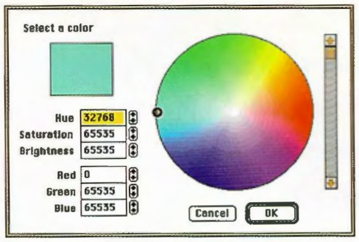
HUE: The basic color group (red, orange, yellow, etc.) or location on the color wheel

CHROMA: Saturation, or intensity

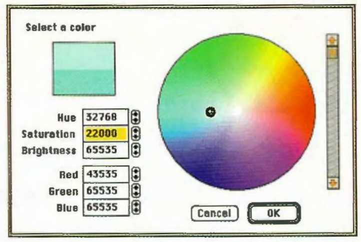
LIGHTNESS: Lightness or darkness



Hue refers to the name of the color and identifies its position on the color wheel. In three-dimensional color space, all the hues are oriented around the center axis. The farther from the center, the more saturated the color, or greater the chroma. The center axis represents lightness, with

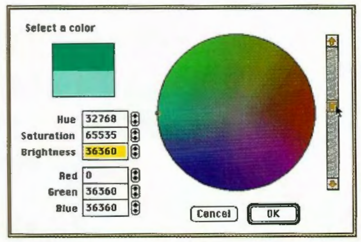


Hue is located around the center.



A color is less saturated (has less chroma) toward the center.

Something familiar to Apple™ Macintosh™ computer users is the color picker which is basically a slice of color space. Notice how hue revolves around the center. In the example, cyan has been selected. The hue is most saturated, or has the most chroma, at the outermost edge. Closer to the center, the hue becomes less saturated. The center axis is controlled by adjusting the brightness value or by the scroll bar. (Here, brightness is used as a term for lightness, or value). By decreasing the brightness value, all colors become darker.



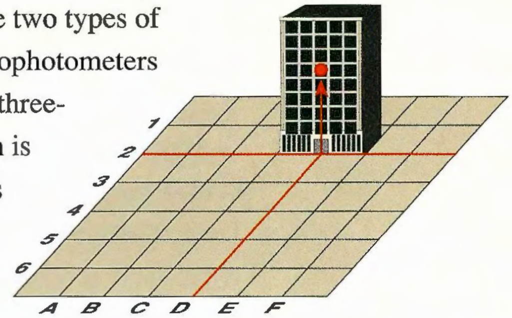
Lightness/darkness is the center axis.

white at the top and black at the bottom. Value is another term often used for lightness/darkness. Most hues have the greatest possible chroma, or saturation, at the midpoint of the lightness axis. At each end of the lightness axis all hues become less saturated, or have less chroma, which means three-dimensional color space is more spherical than cylindrical.

Locating a color in color space is analogous to locating a person in a city using a map with grid coordinates. First, we must know the person's address. If one map coordinate corresponds to the street and the other the avenue, we can plot on the map where the person lives. This gives us a location in two dimensions. Let's say the person lives on the 12th floor of a high rise building. We can plot where the person lives in a three-dimensional diagram with this information. This is similar to locating a color in color space.

In three-dimensional color space, the center axis represents lightness with white at the top and black at the bottom. Most hues have the greatest possible chroma, or saturation, at the midpoint of the lightness axis which means color space is more spherical than cylindrical.

Spectrophotometers and densitometers are two types of instruments used to measure color. Spectrophotometers define a color according to its location in three-dimensional color space. This information is valuable for determining color differences and color matches. For example, a spectrophotometer is used to check the hues of printing inks. Densitometers determine amount, or density, of a color. For example, a densitometer is used in the press room to measure the amount of ink on a printed sheet.



Locating a color in color space is very much like locating a person in a city using a map with grid coordinates. If we know the person's address, and one map coordinate corresponds to the street and the other the avenue, we can locate where the person lives – in two dimensions. If the person lives in a multi-level building, this gives us the location in three dimensions.

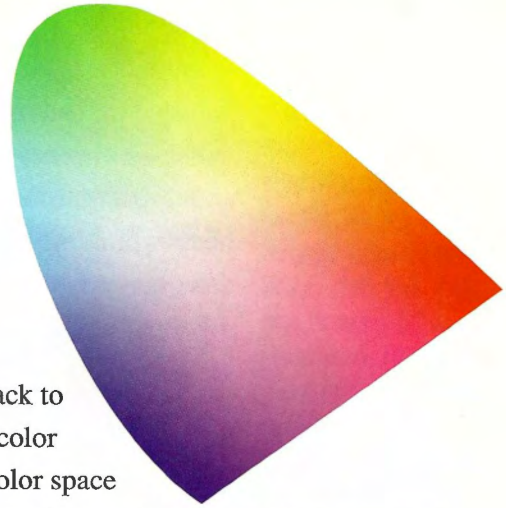
Metamerism

A spectrophotometer can analyze colors in terms of color space coordinates. If two colors have the same coordinates using the same light source, they are considered matched.

Two objects that match under one light source, however, may not match when viewed under another source. This is called metamerism. Remember the example of the shirt bought at a store under fluorescent light that seemed to change color when viewed at home under incandescent light? In this case, each light source caused the same object, the shirt, to reflect a different combination of wavelengths back to the viewer. Consider what might happen when attempting to match the shirt with something else, say a sweater. There is a good possibility that the shirt and sweater may match at the store under fluorescent light, but not at home under incandescent light, or vice versa. Also, the shirt and sweater may look different yet when viewed in daylight — another light source. This happens because different blends of dyes or pigments were used to color the materials in the shirt and sweater. If the shirt and sweater were made using identical dyes or pigments, no metamerism would exist.

This shows how the appearance of an image changes depending on the light source. The light sources in this color rendition light box are 5000 Kelvin in the center (the standard for viewing conditions), fluorescent "store light" on the left, and incandescent on the right. (Courtesy of GTI Graphic Technology, Inc.)

Metamerism is an important variable to consider when making color judgements. This phenomenon is especially significant to those in the graphic arts industry, for example, when comparing a press sheet to a color proof. Using standard viewing conditions reduces the problems associated with metamerism.



Color Space Models

Early attempts to map visible color date back to the middle 1800's. Over the years several color space models have been proposed. Most color space models, however, define color in three dimensions and provide a scheme for representing color in terms of three coordinates. Color space models differ in the same way a city map with one set of grid coordinates differs from another map of the same city that uses a different set of grid coordinates.

The color space model shown above was proposed in 1931 by the International Commission of Illumination, known as CIE. The horseshoe-shaped CIE model is based on measurement of human color perception. A symmetrical model of color space, shown below, called CIELAB has become the accepted standard for the graphic arts industry.

The color space model proposed in 1931 by the International Commission of Illumination, known as CIE, is generally accepted as the world standard for the measurement of color. The CIE color model is based on measurement of human color perception. This model of color space is not symmetrical along the vertical axis. At the midpoint of the vertical, or lightness, axis the CIE model is not circular but horseshoe-shaped.

A symmetrical model of color space called CIELAB proposed in 1976 has become the accepted standard for the graphic arts industry. The CIE and CIELAB models use the same spectrophotometric measurements, but use different mathematical equations to map three-dimensional color space.

Summary

Many involved in the color reproduction process are learning about color the hard way, through trial and error — often at great expense. The information in this book is intended to provide an understanding of basic color principles essential for making informed decisions during the color reproduction process.

It is important to know that color is a visual sensation that involves three elements — a light source, an object and a viewer. Without light, color would not exist. Light that appears white to us, such as light from the sun, is actually composed of many colors. If visible light is divided into thirds, the predominant colors are red, green and blue, which are the primary colors of light.

There are only two ways of reproducing color — additive and subtractive. Additive color involves the use of colored lights. It starts with darkness and mixes red, green and blue light together to produce other colors. When combined in equal amounts, the additive primary colors produce the appearance of white. Subtractive color involves colorants and reflected light. It uses cyan, magenta and yellow pigments or dyes to subtract portions of white light illuminating an object to produce other colors. When combined in equal amounts, pure subtractive primary colors produce the appearance of black.

It is the subtractive process that allows everyday objects around us to show color. For example, a red apple really has no color. Colorants in the apple's skin absorb the green and blue wavelengths of white light and reflect the red wavelengths back to the viewer, which evokes the sensation of red. All color printing processes use the subtractive process to reproduce color. Printing presses use transparent color inks that act as filters and subtract portions of the white light striking the image on paper to produce other colors.

No method of reproducing color can produce the range of colors our eyes can detect. Each color reproduction system is capable of producing a certain range of colors, or color gamut. For example, computer screens (which use the additive process) display a larger gamut of colors than can be produced on press or by most color printing devices. This is important to know when using the computer as a design tool. The limitations of the offset printing process are due to the screening process used to make the image ink-printable and the type of paper on which the image is printed. A color proof is useful as a tool to predict what an image will look like when printed. It can serve as a communication and quality control tool at many steps in the reproduction process.

Because our eyes, no matter how well trained, can be overwhelmed by the many variables that contribute to the color of an image, viewing standards have been established. For the printing industry, standard viewing conditions for color evaluations and comparisons are a 5000 Kelvin light source and a neutral gray surround.

Although we cannot measure how our brains interpret color, we can measure the physical properties that cause the sensation. The fact that color can be measured gives us the means to control color during the reproduction process and thus avoid the expense of trial and error.

Glossary

Additive color system

Means of producing an image by combining red, green and blue light, which are each approximately one-third of the visible spectrum. When added together, red and green light produce yellow; red and blue light produce magenta; blue and green light produce cyan. When added together in equal amounts, red, green and blue light produce white light. Examples of the use of additive color are television screens and computer monitors.

ANS (formerly ANSI)

Acronym for American National Standards (Institute).

Chroma

Attribute of a color that determines its relative strength, or saturation. In color space, the distance away from neutral.

CIE

Acronym for Commission Internationale de l'Eclairage (International Commission of Illumination), a standards-setting organization for color measurement.

CIELAB

Internationally accepted color space model used as a standard to define color within the graphic arts industry, as well as other industries. This three-dimensional model designates L for the lightness axis, A for the red-green axis and B for the yellow-blue axis.

Color gamut

Range of colors that can be formed by all combinations of a given set of light sources or colorants of a color reproduction system.

Color measurement

Methods used for quantifying color, often in terms of coordinates in three-dimensional color space. Used to define and specify color and to determine color differences.

Color picker

Utility for specifying colors on a computer monitor or within a graphics application.

Color proof

Image created using process color inks, pigments or dyes to predict the appearance of the final printed sheet.

Color separation

Process of dividing colors of a continuous-tone color original by making separate digital files and/or screened film intermediates for each color – cyan, magenta, yellow and black. The original image is reproduced by using separate printing plates for each color which contain the proportional amounts of cyan, magenta, yellow and black of the original.

Color space

Scheme for representing color as data. Most color space models define color in three dimensions.

Color space coordinates

Axes used to define the location of a color in three-dimensional color space.

Cones

Photoreceptors in the retina of the human eye that are sensitive to high light levels. The eye has three sets of cones, each sensitive to a portion of the visible color spectrum – red light, green light and blue light.

Continuous-tone image

Photographic image that shows a continuous density range between the lighter and darker areas – without screened dots.

D50 illuminant

Graphic arts standard illuminant in the United States. A list of numbers that define the spectral energy curve for a color temperature of 5000 Kelvin.

Densitometer

Electronic instrument that measures the amount of light transmitted or reflected by a sample then calculates optical density from this data.

Density

Measurement of the light-absorbing quality of a photographic or printed image.

Density range

Difference in density between the minimum and maximum density of an image. Density range is the difference in density reading from the shadow area to the highlight area on a film negative, film positive or printed sheet. See tonal range.

Electromagnetic energy spectrum

Range of wavelengths or frequencies of radiant energy including, in order of increasing wavelength, cosmic-ray photons, gamma rays, x-rays, ultraviolet radiation, visible light, infrared radiation, microwaves, radio waves, heat, and electrical current.

Four-color process printing

Process of reproducing a full-color image by overprinting screened separations for each of the three process colors (cyan, magenta, yellow) and black using process color inks.

Halftone image

Ink-printable image produced by using a contact screen, or a digital scanner, to convert a continuous-tone image into a fixed-grid pattern of different-sized dots which creates the illusion of tones.

High-contrast image

Image with a large difference between minimum and maximum density.

Highlights

Area of an original image or reproduction with the smallest printing dots and/or the least density. On a printed sheet, the areas with minimum ink coverage.

Hue

Attribute of a color that describes its dominant wavelength (such as red, yellow, green, blue) and distinguishes it from other colors. The wavelength of a color in its purest state without the addition of white or black. In color space, hue is arrayed around the center axis.

ISO

Acronym for International Standards Organization.

Lightness

Property that distinguishes white from gray or black, and light color tones from dark color tones. In color space, lightness/darkness is the center axis. Also called value.

Low-contrast image

Image with a small difference between minimum and maximum density. This narrow density range may be anywhere along the total density range.

Midtones

Tonal values of an original or reproduction that fall midway between the highlight and shadow tones.

Offset printing

Term commonly used to refer to offset lithography. The printing process where ink is transferred from the plate to a rubber blanket, then to the paper.

Phosphor dots

Small dots that make up the surface of television screens and computer monitors that emit light when bombarded with an electron beam from a cathode ray tube (CRT). Each pixel on the screen or monitor consists of a triad of phosphor dots, one emitting red light, one emitting green light and one emitting blue light. The CRT can "turn on" different combinations of phosphor dots to create intermediary colors, and can vary the intensity of the electron beam to produce hues with more or less saturation.

Primary colors

Additive primary colors — red, green, blue.

Subtractive primary colors — cyan, magenta, yellow.

Reflective substrate

Canvas or paper in paintings or printed pieces which is usually white. Reflects unabsorbed light back to the viewer.

Rods

Photoreceptors in the retina of the human eye that are sensitive to low light levels.

Secondary colors

Additive secondary colors — yellow, magenta, cyan.

Subtractive secondary colors — red, green, blue.

Screen ruling

Number of rows of dots per inch in both directions of a halftone screen.

Screened image

See halftone image and stochastic image.

Shadows

Area of an original image or reproduction with the largest printing dots and/or the greatest density. On a printed sheet, the areas with maximum ink coverage.

Spectrophotometer

Analytical instrument that measures relative light intensity at many points of the wavelength scale. Most spectrophotometers have a built-in microprocessor or are interfaced with a computer and can plot this data as a spectral curve and calculate color space coordinates.

Stochastic screening

Digital screening method implemented by adding software programs to an imagesetter raster image processor (RIP). Produces very small dots spaced randomly apart. The small dots are approximately equivalent in size to a conventional 1% halftone dot. Dot frequency changes throughout a stochastic-screened image which means screen ruling cannot be used to define the fineness or coarseness of the image. Also called frequency-modulated, or FM, screening. Some stochastic systems randomly place variably-sized dots.

Subtractive color system

Means of producing an image using colorants and a reflective substrate. Uses cyan, magenta and yellow colorants to subtract portions of the white light illuminating an object to produce other colors. When overprinted in equal amounts, cyan, magenta and yellow produce the appearance of black. Color paintings, color photography and all color printing processes are examples of the use of subtractive color.

Tonal range

Difference in density between the minimum and maximum density of an image. Tonal range is the difference in density reading from the shadow area to the highlight area on a film negative, film positive or printed sheet. See density range.

Tone

Lightness/darkness value of a color. Variation of lightness or saturation of a color with no change in hue.

Tone compression

Reduction of the tonal range of the original photographic image to the tonal range that is achievable with the combination of printing process, ink and paper used to reproduce the image.

Tone gradation

Change in density within an image. For screened images, tone gradation is defined in terms of dot area percentage ranging from 1% to 100%.

Tone reproduction

Comparison of the density of an original tone to the density of the reproduced tone.

Value

See lightness.

Visible light

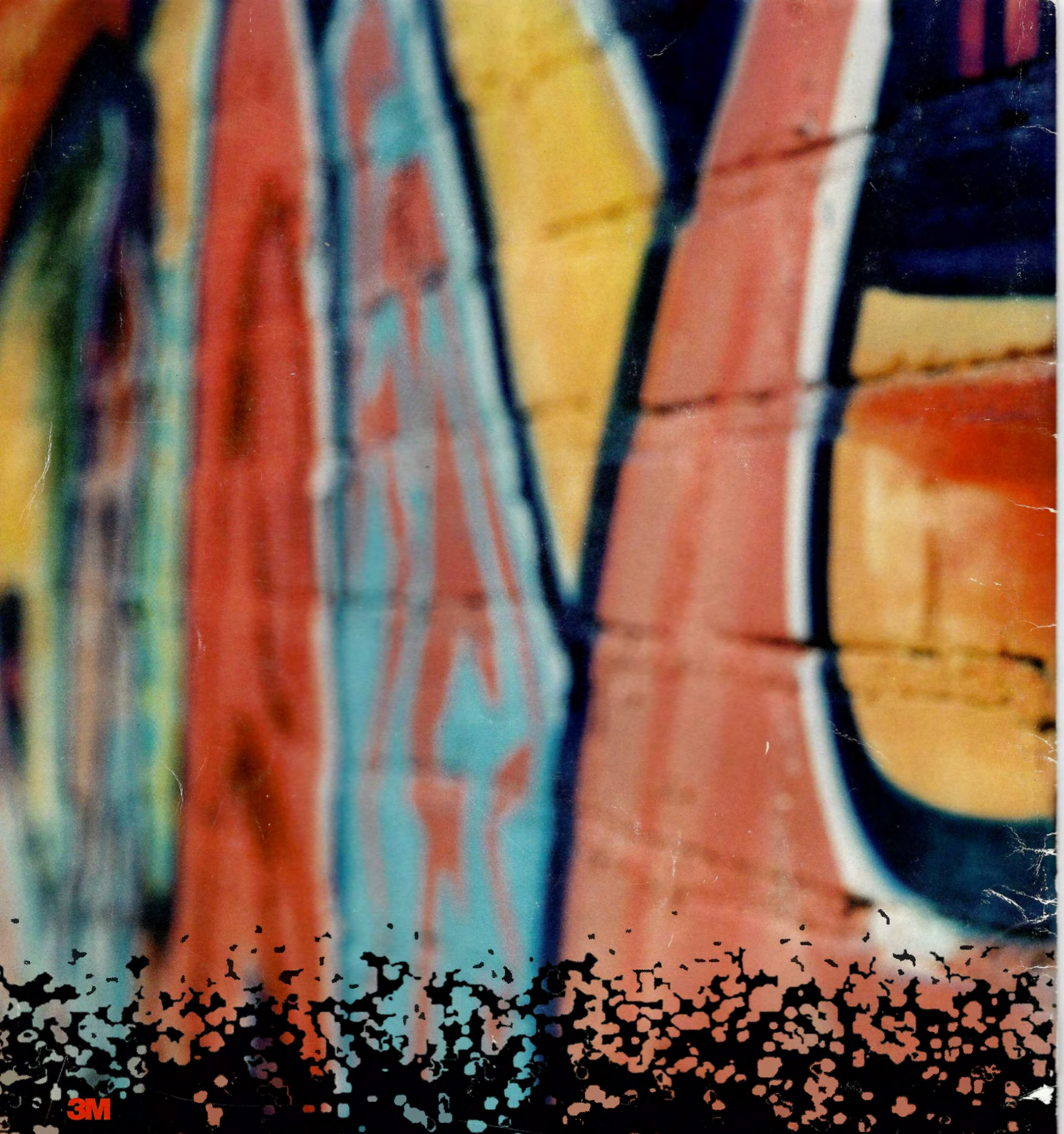
The small portion of the electromagnetic energy spectrum the human eye can detect. Visible light includes wavelengths of light from approximately 400 nanometers to 700 nanometers. (A nanometer is one-billionth of a meter.)

Wavelength

Distance from peak to peak of a periodic waveform such as electromagnetic energy. The wavelengths of visible light are expressed in terms of nanometers (one-billionth of a meter).

5000 Kelvin

Recommended by ANS and ISO as the color temperature of the light source to be used when making color judgements. Most 5000 Kelvin lamps provide a balanced output of red, green and blue light.



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