What is color and How Can it be Measured?

This is the first of a short series of articles about color. Color printing, particularly with toner has become a very important part of the printing and copying market and for the future will represent a significant opportunity for the supplies business.

Understanding Color

Color is the visual affect of the interaction of light on a substance, perceived by a human being. So in order to understand and effectively manage color it is useful to have a basic understanding of all three parts of this process: (1) the nature and quality of light; (2) the way light interacts with material substances; and (3) the way that interaction is perceived by the human eye and brain.

Firstly, light is a form of energy known as electromagnetic radiation (EM). Electromagnetic radiation originates from the Sun, but can also be produced artificially. Although EM exhibits both wave and particle characteristics, it is most commonly described as waves and characterized by its wavelength measured in nanometers (nm). At one end of the EM spectrum are very long radio waves that are of a wavelength of meters in length. At the other end are x-rays and gamma rays, which have wavelengths smaller than a billionth of a meter. The part of the electromagnetic spectrum that our eyes can actually detect which we refer to as "visible light" is a small part of the full spectrum from about 780 nanometers down to 380nm in wavelength.

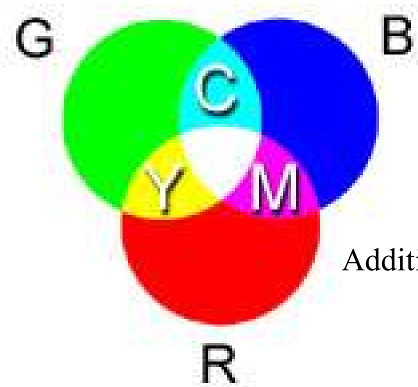
Pure white light is an equal mix of all visible light wavelengths of this spectrum. In real world situations light is seldom in such an even mix. If a greater proportion of the longer wavelength light is in the mix then the light appears reddish. Conversely if shorter wavelengths are in the mix then bluish light will be seen. This tinge of a "white" light is described as its color temperature. The color temperature of a light source will affect the appearance of a scene or of colored objects.

The second element in color is the substance upon which the light falls. Objects in the world are not really 'colored'- they simply absorb, transmit or reflect particular wavelengths from visible light. Different colors occur because each object differs in the way it responds under a light source. For example, a 'white' object reflects all or most of the light that falls upon it, while a 'black' object absorbs all or most of the light. A plant will appear to green because the “pigments” they contain absorb wavelengths from the red and blue parts of the visible spectrum and only allow the 'green' wavelengths to be reflected and seen by the observer. This function of absorbing parts of the visible light spectrum occurs not only when light is reflected from a surface, but also when transmitted through devices like filters or air. For example, a blue filter absorbs the longer green and red wavelengths and allows the shorter blue wavelengths to pass through. Most of the "natural" colors we see in the world around us are capable of being simulated by different intensities of just three fairly narrow bands of the spectrum (either Red, Green and Blue, RGB, or Cyan, Magenta and Yellow, CMY).

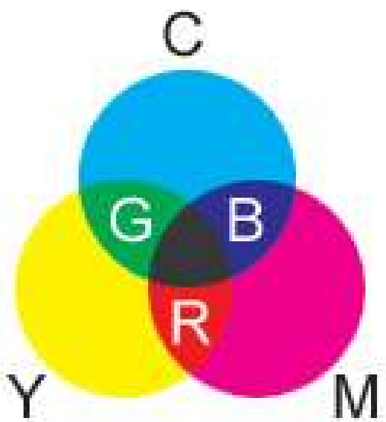
The third element in of color is the human eye. Vision is a very personal, subjective experience, but the basic mechanics are the same for us all. Light enters our eyes through the lens at the front of the eye and is focused onto the retina inside the back of the eye. The retina is covered with millions of light sensitive cells that pass signals to the brain via the optic nerve. There are two types of light sensitive cells in the retina, called rods and cones because of their shape. Each eye has about 120 million rods that are not sensitive to color differences, but record information about lightness and darkness. The approximately 6 million cones in each eye are sensitive to color rather than lightness and are in the centre of the human retina where there is more light. Each cone contains photopigments that are responsive to a particular band of the visible light spectrum. When a cone detects light within its range of sensitivity it produces an electrochemical response. In the human eye there are three sorts of cone that respond to either long, medium or short wavelengths. They're usually called red, green or blue cones because these are the predominant colors within each band. However, the spectral bands they detect are actually quite wide and overlap each other. The way the information from the cones combines controls our experience of color and the outputs from all three cones are determine the color and quality of the light by comparing the responses from the different cones. Because of the way in which our eyes work in that they are particularly sensitive to red, green and blue wavelengths by presenting different intensities of red, green and blue light, it is possible to fool our eyes into thinking that they are seeing other colors. This principle is the basis for color reproduction which enables the reproduction or simulation of a full spectrum of colors from just three "primary" colors: red, green and blue, in 'additive' color processes and their "complementaries", cyan, magenta and yellow, in 'subtractive' color processes.

Additive and Subtractive Color

Colors can be created in one of two ways - additive and subtractive color. In subtractive color, certain wavelengths can be subtracted from the full spectrum by being absorbed by a substance leaving the others to travel into our eyes where they are experienced as particular colors. The subtractive color is the process by which we see most of the color in the world and the subtractive process is the basis for reproductive techniques that rely on reflection, such as color printing. The ambient light hits the page and certain parts of the spectrum are absorbed leaving the remainder to be reflected and experienced by the observer as color.



Additive Color



Subtractive Color

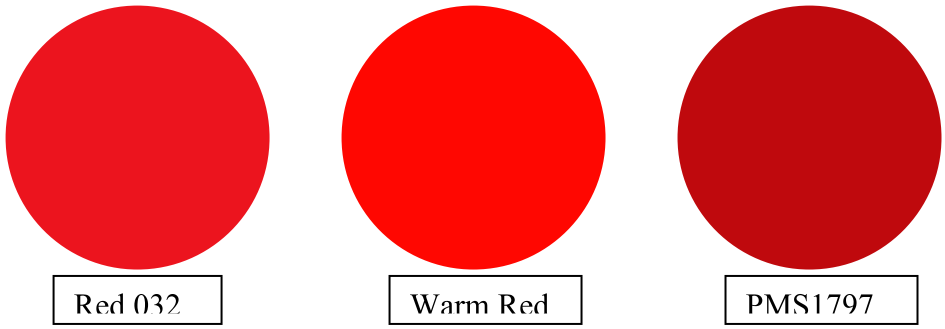
By contrast projected lights that are already limited to particular bands of the spectrum allow their wavelengths to combine to form other colors. This process is known as the additive color process. This is the way color is produced on a television and computer screen. In a white area of a computer monitor for example, if you look at the area using a magnifier you will see that it is actually composed of tiny dots of red, green and blue light. These dots are so small that the light they emit is integrated by our eyes and appears to be superimposed. The red, green and blue dots at full strength, when integrated by our eyes, give is the visual impression of white. Varying strengths or intensities makes our eyes and brains interpret the light as other colors. Of course the choice of red, green and blue is because they directly match the way in which our eyes detect color and light as described above.

The difference in choice of the basic three colors between additive and subtractive color is not accidental of course. In subtractive color processes, like printing, red green and blue would not the best choice for these basic or primary colors. This is because these colors would subtract too much light. In a subtractive color system red, green and blue are incapable of producing the full range of colors we can see. The best choices are cyan, magenta and yellow. This choice is because these colors have 'complimentary' relationship with red, green and blue. Red, green and blue absorb most of the spectrum of incident light leaving only one band of wavelengths to transmit or reflect. Cyan, Magenta and Yellow, by contrast, subtract only one band of the spectrum, red, green or blue, respectively leaving the remaining wavelengths to reflect and mix together. 'Cyan' color is actually a mixture of light wavelengths from the green and blue parts of the spectrum. A dot of cyan ink will subtract the red wavelengths from white light, leaving the green and blue wavelengths to reflect and combine to form the color we call cyan. By changing the amount of cyan, magenta and yellow, it is possible to create all of the other colors we would want to print. For example if we wanted to create red, for example, we would overlay a dot of magenta and a dot of yellow. The magenta would absorb green and reflect both red and blue light. The yellow would then absorb the blue, allowing just the red to reflect into our eyes. In theory, we could add a dot of cyan on top of these and this would absorb the red, allowing no light at all to escape and produce black, but in practice, because inks are seldom pure in color, a little light would be reflected and the black wouldn't appear completely black but a muddy gray. That is why printers include black to make sure the printed image is as dark as required. Digital images for printing are typically held within a CMYK color space where K is the mnemonic for black.

What Color is This?

We live in a colorful world. There is color everywhere around us and these colors come in an infinite variety. But how do we say with any precision what a particular color actually is? It is not easy like the length of a piece of paper or the weight of toner in a bottle. There is no common physical metric for measuring color and this means that if you ask the question, “What color is that?” everyone will give a similar but different answer. An example would be that if we talk to different people about “a red balloon” each person will have in their mind a different image of the color of that “red balloon.” The reason for this is that every persons perception of the color of any object is based on exactly how their eyes work in visualizing color compared to others and past experience of “red balloon.” This is the problem with describing color. In printing we need to be able to be precise in the definition of any specific color removing these differences and ambiguities so that we are able to print with precision and achieve specific printed results.

Try this! Cover up two of the three circles below and describe the color. How do you describe the color? All three are red, but what kind of red? Scarlet, crimson, ruby, cherry, wine red, garnet, dark red, dark pink? It is so very subjective how the red circles are perceived. They are all red! The three circles at first glance look the same, but with closer examination they are different and the color of the circle on the right is somewhat duller and the color of the left hand circle is more blue shade red than the one in the middle. They are all red. The color of the middle circle appears vivid.



The color of any object depends on individual perception and subjective interpretation. Even if a group of people look at the same object, they will unconsciously use different references and experiences and describe the same color but will do so differently. As a result defining a particular color in words is extremely difficult and vague. If we were to call the center circle bright red and ask to a group of artists to paint a bright red circle none of them would actually paint a circle of precisely the same color. Expressing color in words is too complicated and difficult.

Other Problems in Describing Color

A whole variety of viewing environment conditions determine what a color actually looks like. An apple or a plum that looks delicious in the sun at a Farmers Market just doesn't look so good in the light when you get it home. Lighting conditions when an object is viewed, whether it is in sunlight, fluorescent light, tungsten light, or any other kind make the same apple or plum appear different in color. Try it with the circles above if you can. Take them over to the window or into a different room or part of the room. You'll see that the color changes slightly.

Everybody's eyes are different. They differ in sensitivity and color perception. Even those people that are determined by test not to be "color blind" and are considered to have "normal" color vision may have a bias toward red or blue shades. This is also not constant for any individual. Changes in a person's eyesight progress with age and other physiological factors. The red you perceive today may not be the red you perceive in the future because of these changes.

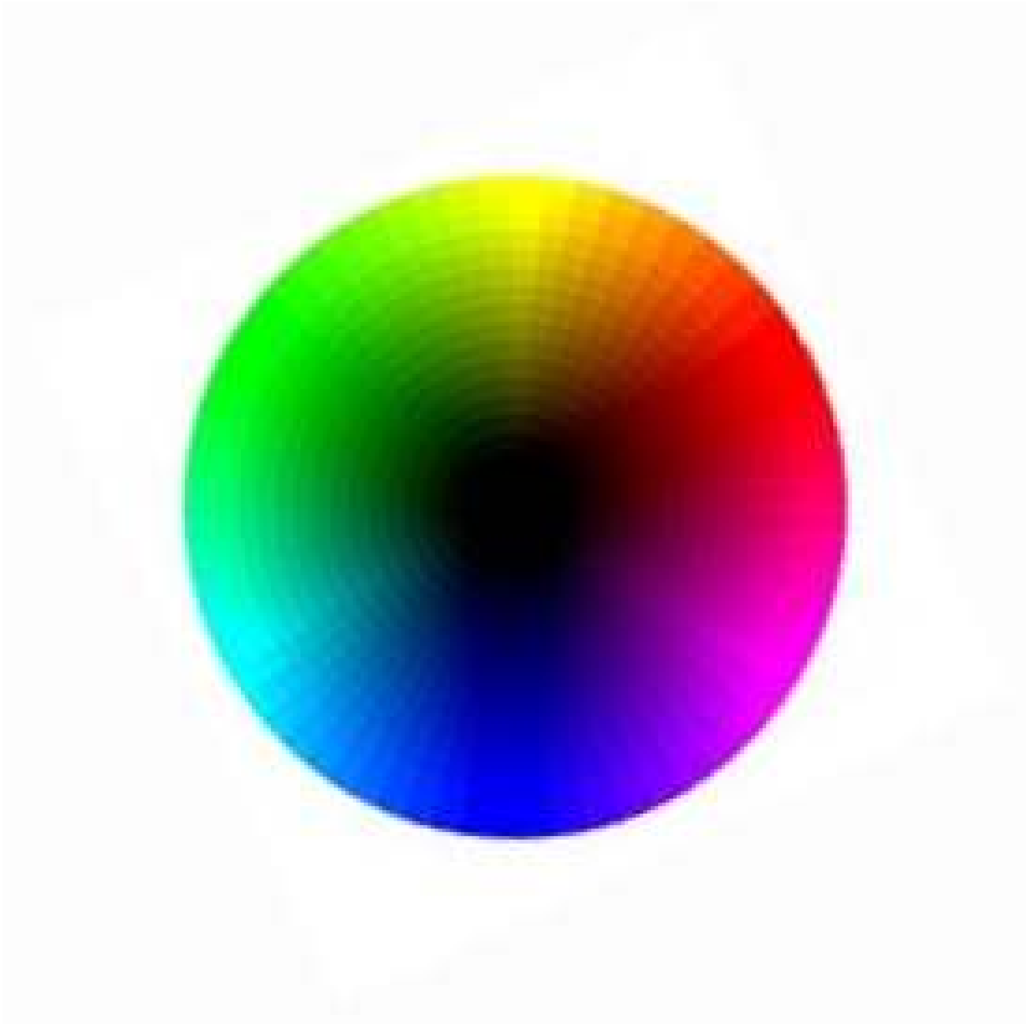
Size matters! If you go to the DIY store to buy paint you probably will look at a shade card to select a color. It is not unusual that, even though you have studied the shade card well that after looking at this small color sample which looks good, when you use it on a wall in your house it looks too bright. Large areas of color tend to appear brighter and more vivid than when the same color is viewed in a smaller form.

Another viewing condition is that objects are not always viewed in isolation. If the red circles above were to be printed on different color papers of the same type, if the paper were brighter the circles would appear duller. Conversely, if the circles were printed on a less bright or even a dark background they would appear brighter. This is called the contrast effect.

The angle at which a color is viewed is also important. Viewing the circles from a slightly different angle can make the color appear brighter or darker. This is also material dependent and inks and toners of different composition can have highly directional characteristics. For accurate color communication, the viewing angle and the illumination angle must be constant for accurate color definition.

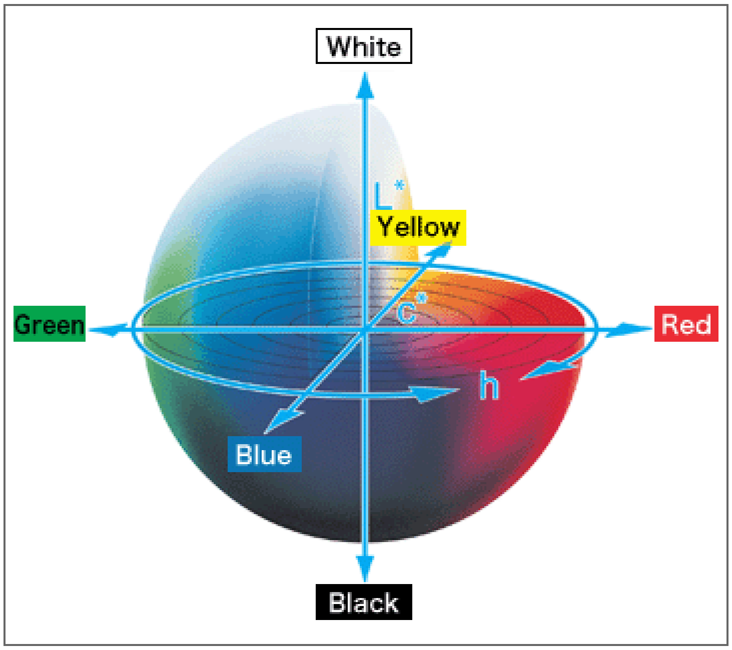
However, there is a method by which colors can be accurately defined and this is especially helpful in fields such as printing. When colors are measured, they can be expressed in terms of their hue(color), lightness(brightness), and saturation (vividness). This precise color measurement and definition is an essential tool in communication about color and eliminates color-related problems in many fields of endeavor.

Hue, lightness, and saturation are the three parameters in the measurement of color. In normal description of color where imprecision is tolerable we can say that cherries are red, lemons are yellow and the sky is blue. It doesn’t matter here what the precise color is we can visualize what the speaker or writer means in our own interpretation. This is not good enough for use in disciplines that are involved with color science. Hue is the term used to classify what color we want to specify e.g. red, yellow, blue, etc. and although yellow and red are two completely different hues, mixing them together makes orange, mixing yellow and green makes yellow shade green or green shade yellow, mixing blue and green makes blue shade green or green shade blue, and so on. This range of hues gives us what we call a color wheel as shown below.



From: www.realcolorwheel.com/grayscale.htm

Colors can be classified as bright or dark colors when their lightnesses is compared. For example, the yellow color of a lemon and a grapefruit, typically the yellow of the lemon is much brighter than the grapefruit. However, if you compare the yellow of that lemon with the red of a cherry the hues are different but the lightness of each can be measured independently of hue and compared.



Now take a look at the diagram above. It shows a three dimensional color space in which our two dimensional color wheel is a cross section of that spherical space perpendicular to the lightness (black to white) axis. Lightness increases toward the top and decreases toward the bottom and the lightness of colors changes vertically.

Further than this, how do you compare the yellows of a lemon and a mimosa blossom? You could say the yellow of the lemon is brighter, but more likely here, it is more vivid. This difference in colors is one of color saturation or vividness. This is completely separate from both the hue and lightness of a color. In the three dimensional color space above we can see that saturation changes for any color as the horizontal distance from the center changes. Colors near the center are dull and become more saturated they move away from the center. So we have three axes or parameters with which to describe and measure colors – hue (position around the disc that is the color wheel), lightness (position on the axis perpendicular to the color wheel disc) and saturation (distance from the center of the sphere.)

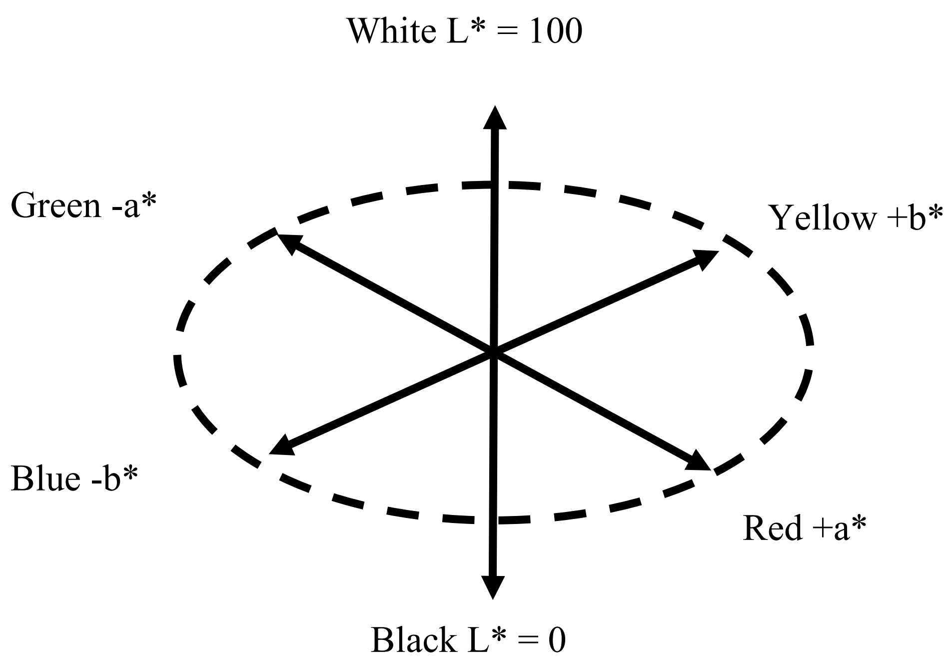
Color Measurement

There have been many methods of measuring color and expressing it numerically, often using complex formulas, trying to make it possible for anyone to communicate color more easily and accurately. "Color space" systems are now used throughout the world for color communication. These methods attempt to provide a way of expressing colors numerically, in much the same way that we express length or weight.

One method is based on XYZ tristimulus values and the associated Yxy color space form the foundation of the present CIE color space. The concept for the XYZ tristimulus values is based on the three-component theory of color vision, which states that the eye possesses receptors for three primary colors (red, green, and blue) and that all colors are seen as mixtures of these three primary colors. The CIE in 193l defined the Standard Observer to have the color-matching functions, x(λ) ,y(λ), and z(λ). The XYZ tristimulus values are calculated using these Standard Observer color-matching functions. The tristimulus values XYZ are useful for defining a color, but the results are not easily visualized. Because of this, the CIE also defined a color space in l93l for graphing color in two dimensions independent of lightness; this is the Yxy color space, in which Y is the lightness (and is identical to tristimulus value Y) and x and y are the chromaticity coordinates calculated from the tristimulus values XYZ.

However, one of the most widely methods used today is the L*a*b* color space, (also referred to as CIELAB) devised in l976 to provide more uniform color differences in relation to visual differences. This color space is popular for measuring object color and is widely used in virtually all fields. It is one of the uniform color spaces defined by CIE in 1976 in order to reduce one of the major problems of the original Yxy color space that equal distances on the x, y chromaticity diagram did not correspond to equal perceived color differences.

The L*a*b* color space is today the most frequently used standards for measuring the color of any object and is widely used in all fields. In this color space, L* indicates lightness and a* and b* are the chromaticity coordinates. Chromaticity is the



classification of a color with reference to its hue and its purity, i.e., its departure from what would be white light.

Above is diagram showing the axes of the L*a*b* color space.. In this diagram, the a* and b* indicate color directions: +a* is the red direction, -a* is the green direction, +b* is the yellow direction, and –b* is the blue direction. The center point is achromatic and as the a* and b* values increase and the point describing the color moves away from the achromatic center, the saturation of the color increases. In the vertical direction along the lightness axis as the point moves upward the color gets lighter and conversely as the point moves lower the color gets darker.

If we measure the color of the middle circle using the L*a*b* color space, we obtain specific values for each of these parameters. Firstly, if we measure the a* and b* values, which could be for example a*= +46.65 and b*= +l3.22 the position shows the chromaticity of the circle. The measured L* value shows the lightness of the color which might be in this case L* = 42.99. These measured parameters define exactly the color of the middle circle so that it can be matched and replicated for any particular purpose.

In the next installment of this article we will consider the way in which these principles of color science and measurement are used in color printing.