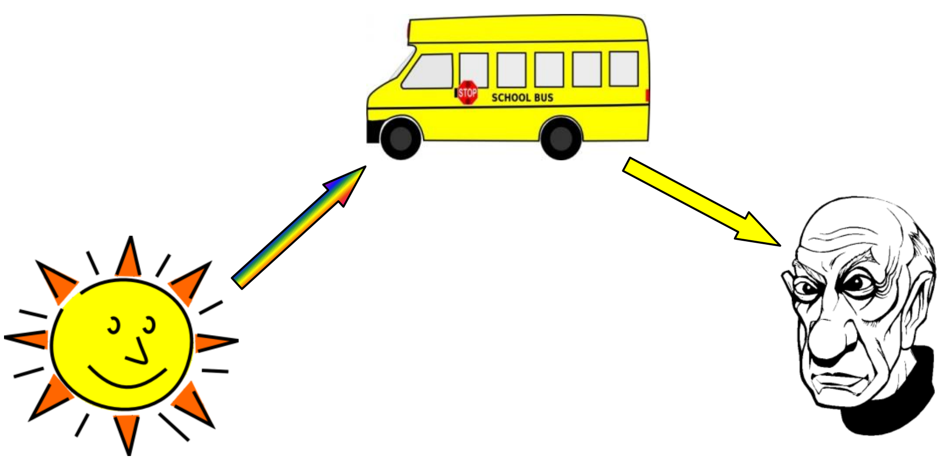
# Kalcor University
## The Art & Science of Color Measurement

What size Crayon box did you grow up with? 8? 24? … Or maybe the 64 crayon box with built in sharpener? Your pallette may have gown in sophisitication from yellow to dandelion and purple to Razzmic Berry. Today, a visit to the paint department at Lowes or Home Depot has the same dizzying effect – so many colors to choose from.

A critical and particularly challenging part of a paint formulator's job is freqently to produce the perfect shade – the exact color the customer needs. Maybe it is to perfectly match an exisitng color like John Deere Green, or maybe to devise some fashionable new look for a cellphone or perfume bottle. In either case understanding how color is perceived, and how it is measured is fundamental to talking about color. This aper briefly describes the sceince of color perception and measurement. Because as every engineer knows – you can't control it if you can't measure it.

**<u>How We Perceive Color.</u>**

There are three components necessary for us to see color; a light source, an object and our eye. Take this simple example:

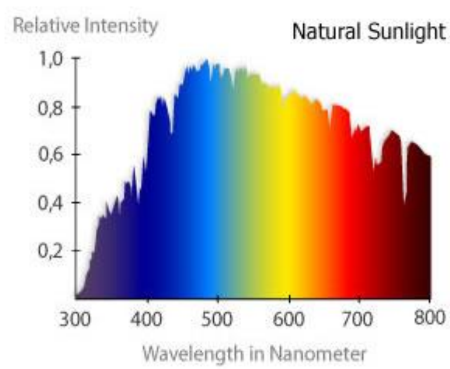



Here, Picasso sees the yellow schoolbus when sunlight strikes the bus and reflects yellow light to his eyes.

To measure color with some sort of apparatus we must substitute for these with mechanical components. Instead of the sun, a school bus and our eyes, color measurment systems incorporate a light source, our test specimen and color sensors. And, to describe color more precisely than using qualitative descriptions like redder or greener, we have devised a scale by which colors can be compared quantitatively.

**Light Sources**

We normally think of light sources as emitting some kind of white light. But we recall from Newton's famous prism experiment that white light is actually a mixture of many colors. We see a rainbow after a rainstorm because water droplets acting like millions of tiny prisms divides the white light up into it's constituents by refracting them. We might even recall the R-O-Y-G-B-I-V mnemonic for recalling that the rainbow colors go from red to violet in a continuous spectrum. In fact, by measuring the wavelength of these various colors, we know that the visible spectrum ranges from about 400 to 700 nanometers.

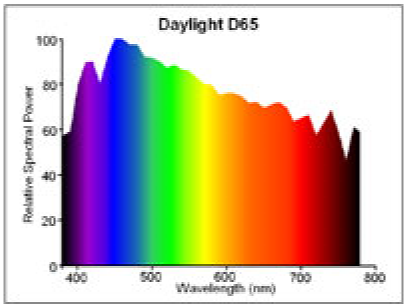



But artificial light is not exactly the same as sunlight. And various kinds of artificial light sources appear differntly to our eyes as well. From bright tungston lamps, to the blue cast of flourescent lights to the yellow glow of sodium streelights, we regonize that the light sources are different and that affects how an object looks to us. Many people demurr from buying an expensive suit in a department store until they can see it in more "natural" lighting. Ladies makeup mirrors often have settings for different kinds of light.

The two photos at right demonstrate the effect of the light source on two identical swatches of paint. The color cards in the top and bottom photos are the same – only the type of light source has changed. To describe color in a repeatable fashion, we must standardize the light source, describing accuratley its spectral output.

One popular means to describe light sources is to compare their color temperatures. The color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of comparable hue to that of the light source. Color temperature is conventionally stated in the unit of absolute temperature, the kelvin, having the unit symbol K.

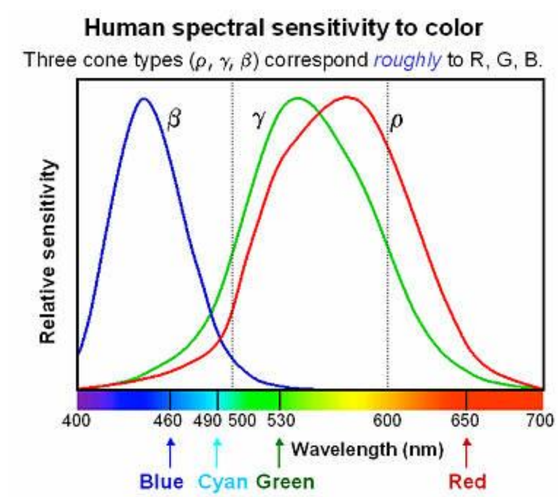
Color temperatures over 5,000K are called cool colors, while lower color temperatures (2,700–3,000 K) are called warm colors. Daylight has a spectrum similar to that of a black body with a correlated color temperature of 6500K.




Natural daylight is often a preferred light source for evaluating color and so articifical lights have been developed that replicate the specra of daylight. The CIE Standard Illuminant D65 is a common standard illuminant defined by the International Commission on Illumination (CIE). D65 corresponds roughly to a mid-day sun in Western Europe / Northern Europe; hence it is also called a daylight illuminant. D65 lamp sources are therefore common to color measurment equipment, and color inspection booths with daylight settings rely on D65 lamps to replicate natural sunlight. The term illuminant metameric failure is sometimes used to describe situations where two material samples match when viewed under one light source but not another.

**The Object**

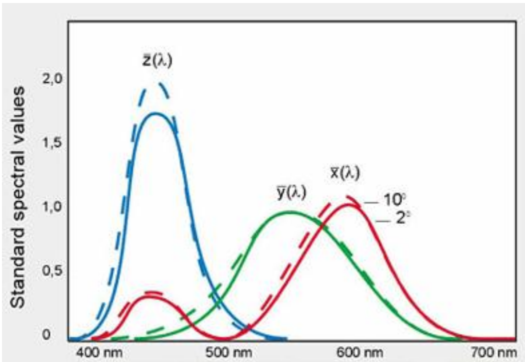
Objects modify light that strikes their surface. Different materials absorb various wavelenghts of light and reflect others. Coloroants such as dyes or pigments selectively absorb certain specific wavlengths awhile relfecting others. The wide range of organic and inorganic pigments avaialble to the formulor creates a jumbo Crayon box they can choose from. Blending these pigments like an experienced perfumer does with exotic and subtle scents can create great beauty of a disasterous mess. This is truly the art of the color matching or creation process. Many aspects of paint pigments affect their appearance and performance in paints. The chemical structure and its interaction with other pigments and additives, the fineness of the pigment grind, the manner in which the pigment can be dispersed




**Color Sensing**

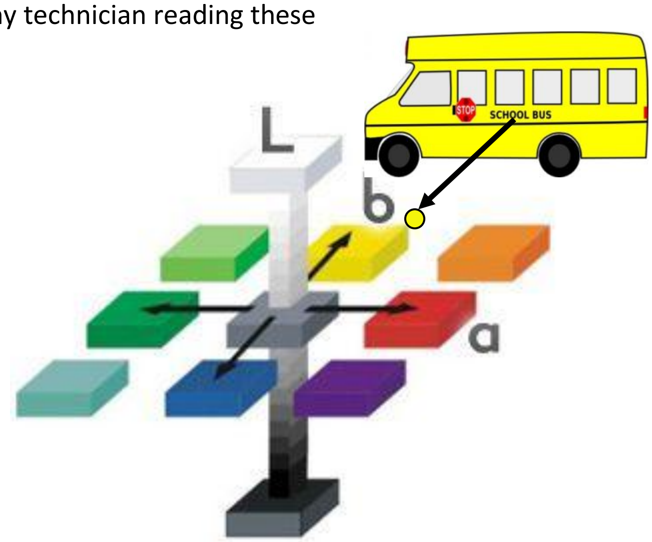
The final component of the color measurment system is the "eye" of the apparatus. In fact a great deal of work has been done by scientists and engineers to develop sensors that mimic the way our eyes perecive color. The human eye, which uses rods and cones as receptors for perceiving color, has a characterisitc spectral sensitivity. It is the failure of different rods or cones causes selective color blindness.

To construct a machine which "sees" colors as we do engineers tune the spectral sensitivity of color sensors to replicate the same sensitivity of human eyesight. The CIE 1931 XYZ $2^{o}$ and subsequent $10^{o}$ color spaces are an engineered replication of human vision and form the basis for today's quanitative color measurement systems. By utilizing a series of color sensors that combine to produce the same response as a human eye, colors are interpreted by a machine as they would by a human observer. Measuring color using the CIE XYZ tristimulus system involves tedius computations where the individual values of the light source, pigment and sensors and then summiing the values to get an overall measure of color.




Because the XYZ scale is not an intuitive measure of how we pereceive color it has been modified over time and supplemented with other scales such as the Hunter L,a,b coordinate system which characterizes color on a 3-axis system comprised of the L – or luminous axis (a measure of how white or black something is), the a-axis which measures color between expremes of red and green, and the b-axis which measures along an axis defining blue and yellow. Like geometric coordinates, tany color can be described by its values on the L,a,b color axes.

In our school bus example, we might describe the yellow color at L=+60 (on a 100 scale), a= +20 on the red-green axis, and b= +32 on the yellow – blue scale. Any technician reading these L,a,b numbers with a D65 light source will replicate the same school bus yellow color.




Just as mathematically you can calculate the distance between two points on a 3-dimensional coordinate system, so can you calculate the “color distance” between two different color points in this measurment system.

In coordinate geometry, the distance between two points in a 3-dimensional space is given by:

$$\sqrt{(\Delta x)^2 + (\Delta y)^2 + (\Delta z)^2}$$

Similarly, the distance between two colors on the L,a,b system of coordinates is given by a similar expression:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

This expression gives us the “color distance” between two colors, measured in “delta-E” units. For many tight color requirments a difference of only a few delta E are accpetable. It’s clear from this expression how stringent such a requirement is. Many studies show that a difference of one delta E is barely perceptable to event the most rained eye.