Applications Note

Insight on Color **Vol. 12, No. 5**

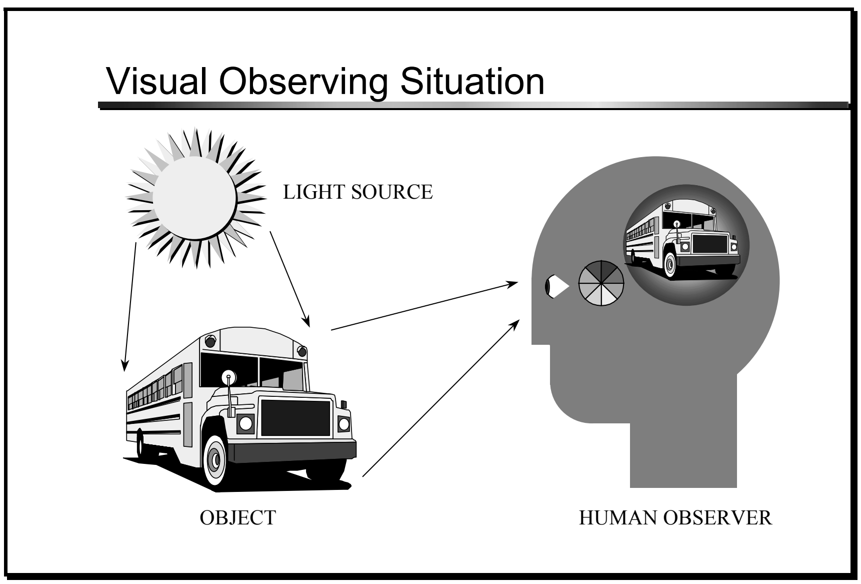
What is Color and How is It Measured?

The most important part of HunterLab's business is helping our customers to measure color. In this Applications Note, you will learn more about why colors appear as they do and how they are measured.

The Visual Observing Situation

There are three components necessary for the perception of color:

- **Light**, which supplies the spectral energy required for viewing color. We cannot see color in the dark.
- **An object**, which modifies the spectral energy from the light source. The different colors affect the light in different ways. For instance, red objects modify the light differently than green objects.
- **An observer**, whose eye and mind perceive color and appearance.



Color may be evaluated subjectively (visually) or it may be evaluated objectively, as with a spectrophotometer or colorimeter. In order for color to be quantified objectively, all three components of the visual observing situation must be taken into account.

Light

In the visual observing situation, a light source emits radiant energy in the form of visible light. Examples of light sources are the sun, a table lamp, and an overhead fluorescent light.

This visible light is a very small portion of the broad electromagnetic spectrum that includes X-rays, ultraviolet and infrared light, and radio waves. The wavelengths of light visible to the human eye range from about 400 to about 700 nanometers (nm). The entire electromagnetic spectrum is illustrated below.

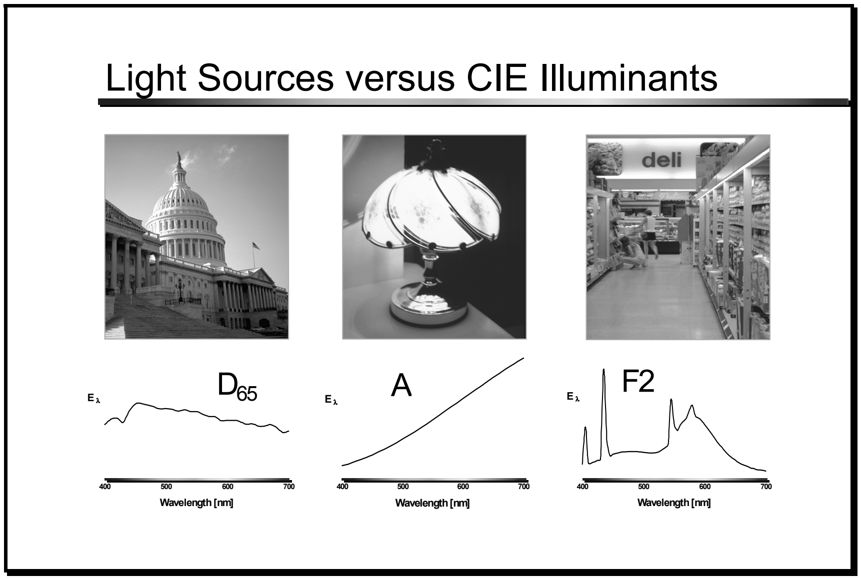
The type of light in which an object is viewed can definitely affect its appearance. Does the fluorescent lighting in a department store dressing room really show you how an outfit looks on you, or do you have to wait until you get outside to judge the color? Does a car look the same under bright sunlight as it does under a dim street light at night? The lighting under which color is judged is very important.

The light source is one of the elements that must be controlled in order to accurately judge color. Realizing this, the CIE (Commission Internationale de l'Eclairage, or International Commission on Illumination) has developed standardized illuminants for color judgment by human observers or measurement by instruments. Each illuminant has a different composition of various wavelengths of visible light. If you plot the relative energy of a light source at each wavelength, you create a spectral power distribution curve for that source, as shown below for several illuminants. The most common illuminants are:

- **A** - incandescent, or tungsten, light
- **C** - north sky daylight, or average daylight
- **D65** - the most commonly-used daylight illuminant; average of noon daylight all over the world
- **D50** - horizon light (sunlight at sunrise or sunset)
- **D55** - mid-morning or mid-afternoon daylight
- **D75** - overcast
- **F2, Fcw, CWF, F** - cool white fluorescent
- **TL4 or TL84** - a custom fluorescent; Phillips TL84 fluorescent lamp found in Marks and Spencer stores in Europe

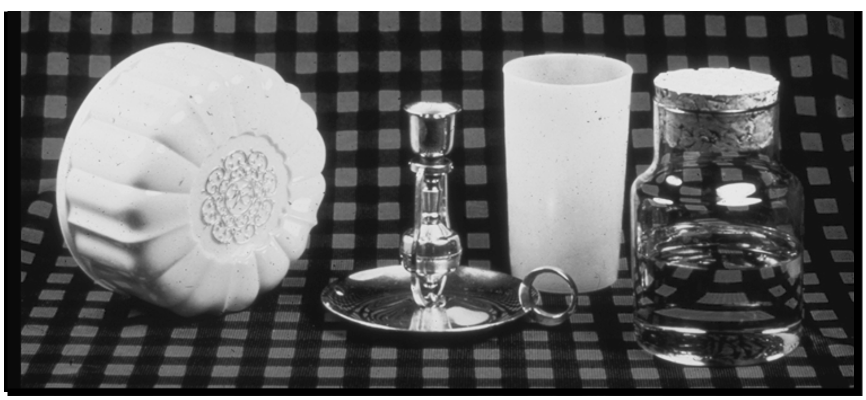
- **Ultralume 3000** - a custom fluorescent; Westinghouse fluorescent lamp found in many Sears stores in the United States.

Illuminants are formulas used for mathematical manipulation of color data. They are not realizable physical light sources.



Object

Objects that are viewed themselves contribute to perception of color and appearance by modifying the light from the light source. Colorants (pigments or dyes) in objects absorb some wavelengths of the light and reflect or transmit other wavelengths. For instance, a red object reflects the red wavelengths of light and absorbs all other wavelengths. It is the reflected red light that causes us to see the object as red. Also, the surface roughness of an object determines the degree of first surface scattering, which creates the perception of gloss or shininess.

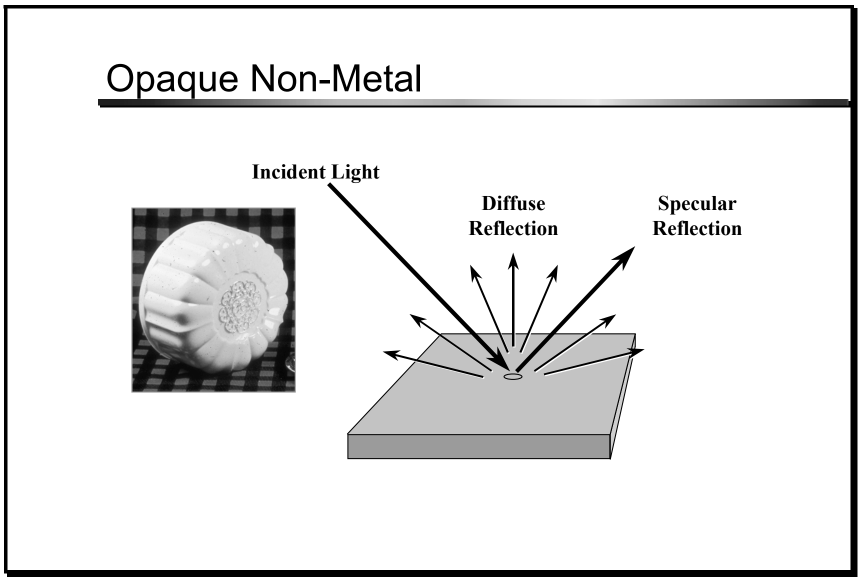


Almost all objects can be placed in one of four categories, depending on how they interact with the light source. These categories are described below.

- Opaque nonmetal
- Opaque metal
- Transparent material
- Translucent material.

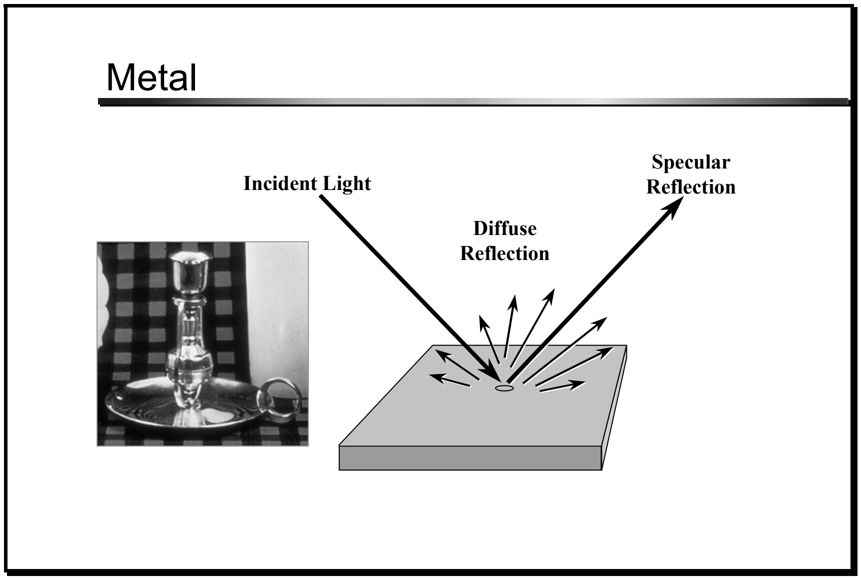
Opaque Nonmetals

Opaque nonmetals are nonmetallic objects that do not allow any light to pass through, such as a wooden table top, plastic car bumper, or the cover of a book. With these objects, two different types of reflection play a role in appearance. Specular reflection is direct reflection of the light beam in an equal but opposite direction. This is mirror-like reflection, "highlight," or gloss you might see on an object. Specular reflection makes up about 4% of the total reflection of a smooth opaque nonmetal. The remaining 96% of reflection is diffuse reflection, the scattering of the source light in all directions by the object. An object's color is seen in the diffuse reflection. To measure an opaque nonmetal's *color*, you would need to measure the diffuse reflection. To measure its total *appearance*, you might want to measure the diffuse AND specular components of reflection.



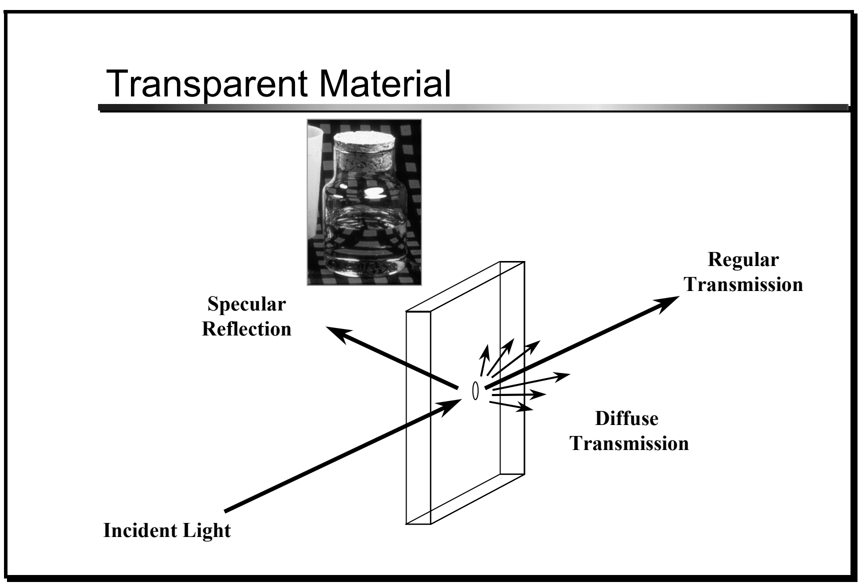
Opaque Metals

Opaque metals are metallic objects that do not allow any light to pass through, such as a chrome faucet, aluminum pan, or a gold candlestick. Painted metals, such as car bodies, are not included in this category, but are opaque nonmetals. Only bare metals are opaque metals. For these types of objects, as for opaque nonmetals, specular reflection and diffuse reflection are key. However, for metals, color *and* gloss are seen in the specular reflection, which makes up a large portion of the reflection. A small amount of diffuse reflection results from imperfections in the object's surface that cause the specular reflection to scatter. Brushed metals provide a good example of this. In this case, color is also seen in diffuse reflection.



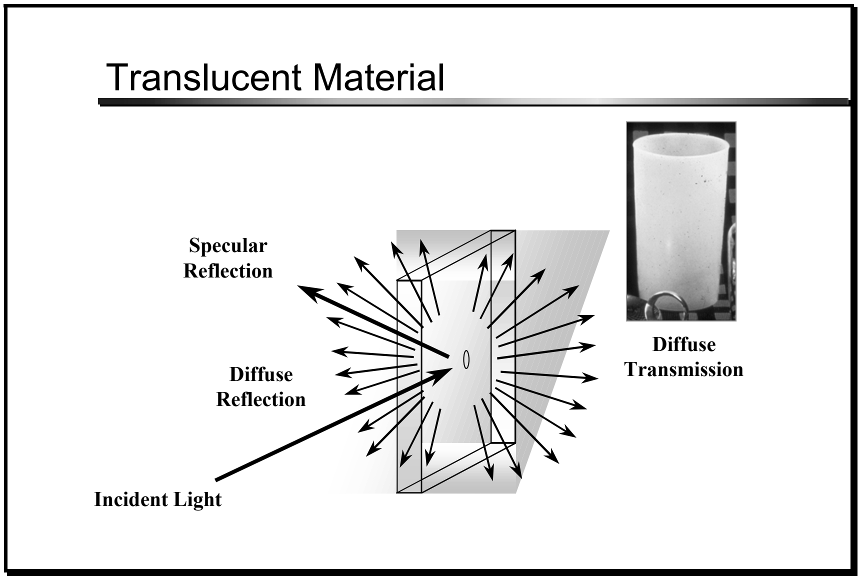
Transparent Materials

Transparent materials allow much of the light from the light source to pass through. Generally, these are objects through which you can see clearly. They can be either solid or liquid. Examples are a glass window and water. With these objects, some light is specularly reflected and is seen as gloss on the object surface, and the remaining light is transmitted through the object. Regular transmission is the transmission of the light straight through the object, and diffuse transmission is scattering of the light as it passes through the object. Total transmission is regular transmission plus diffuse transmission. Color of a transparent object is seen in the regular transmission. If diffuse transmission occurs, it also contains some color and is responsible for any hazy or cloudy appearance. To measure a transparent material's color, you would measure regular or total transmission. To measure gloss, measure specular reflectance. To measure haze, measure diffuse transmission.



Translucent Materials

Translucent materials can also be solid or liquid. They allow some light to pass through, but specularly and diffusely reflect light as well. You can see light through translucent objects, but cannot see images clearly through them. Examples include orange juice and a single sheet of paper. These objects are optically complex, combining characteristics of both opaque nonmetals and transparent materials. Gloss is seen in specular reflection and color is seen in diffuse reflection when the light is in front of the object. Color is seen in diffuse transmission when the light is behind the object. Translucent objects are not easy to measure since any variations in their thickness or background will affect their color.



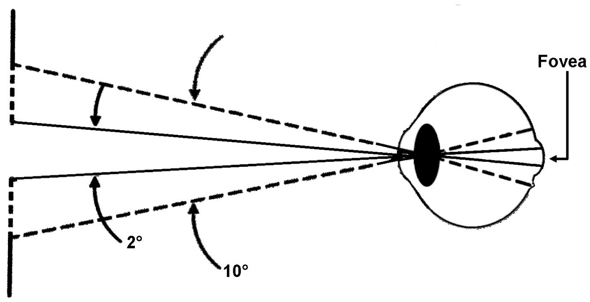
When examining or measuring an object for color and appearance, it is important to categorize it as an opaque nonmetal, opaque metal, transparent material, or translucent material. The category of an object gives important clues about how it should be measured.

Observer

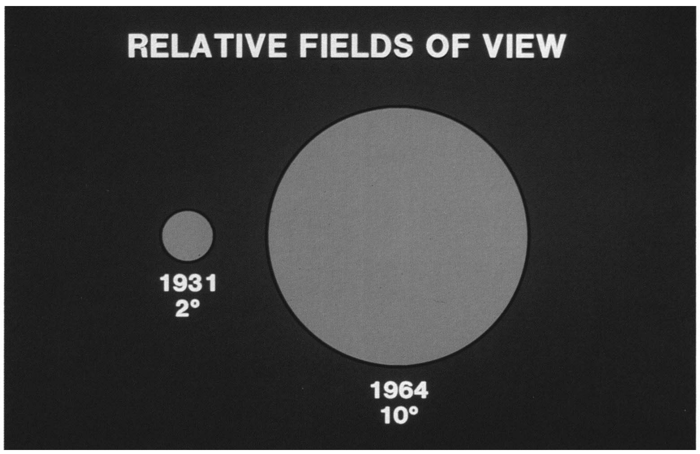
The third component of visual observation is the observer. By "observer" we mean a human eye which receives the light and the brain which provides the perception for the vision. Since different humans perceive color and appearance in different ways, subjectively, attempts have been made to "standardize" the human observer.

Wright and Guild performed experiments using human volunteers to assess their color vision and develop an average, or standard, observer. In 1931 they published the 2° CIE Standard Observer function based on their research. The function is called 2° because their experiments involved having the subjects judge colors while looking through a hole that allowed them a 2° field of view. In 1931, it was believed that all the color-sensing cones of the eye were located within a 2° arc of the fovea. Thus, the 2° observer was chosen.

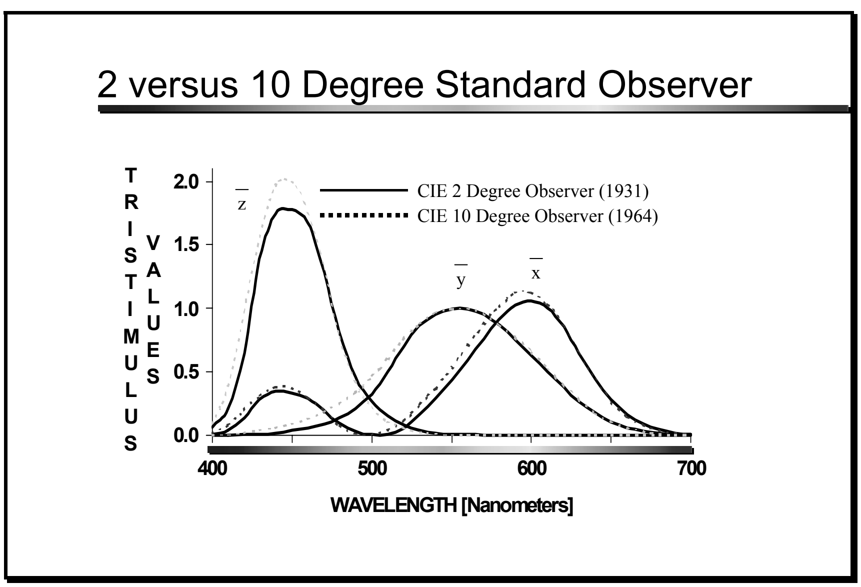
2° - 10° Observer



By the 1960s, it was realized that cones were present in a larger area of the eye than previously believed, and so in 1964, the 10° Standard Observer was developed. The 10° Standard Observer is currently believed to best represent the average spectral response of human observers, although the 2° Standard Observer still has its place for measurement of such objects as road signs, for which optimal viewing conditions might not be achieved. The relative sizes of the two fields of view are shown below.



The standard observers are used in the form of mathematical functions of the human response to each wavelength of light. The observers can be graphed as shown below.



Taking Light, the Object, and the Observer into Account

When evaluating color visually or instrumentally, all three elements of the observing situation should be taken into account. The light is quantified using the function (mathematical formula) of the chosen illuminant. The nature of the object indicates the proper measurement method and the object itself modifies the light to yield a particular color. The observer is quantified using the function of the chosen standard observer. When measurements are taken and expressed in terms of a *color scale*, all three factors — light, the object, and the observer — are taken into account.

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