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Color Standards – What are they?

There are a bewildering amount of color standards available, each with a set of properties that will make it very good for some applications, and possibly very bad for others. This note will focus on the physical properties of standards, and set the stage for other discussions that will connect these properties to various applications.

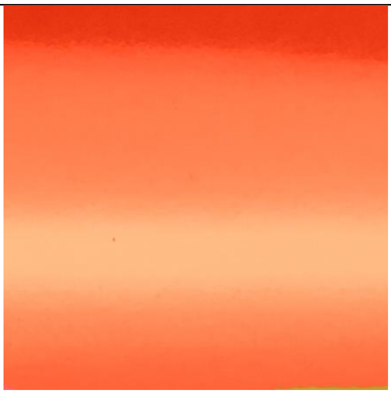
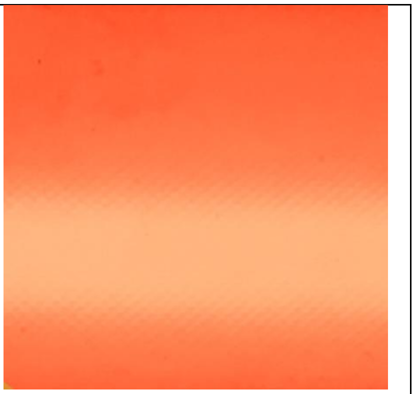
First let’s be clear about the broad set of applications these standards are applied to: the wavelengths in the range of 300-800nm. That is: near ultraviolet, visible, and very near infrared.

Introduction

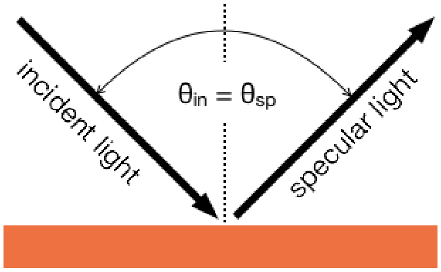
In addition to providing general knowledge on color standards, this white paper is intended to guide you through the selection of such standards to use a references as a part of a color measurement program. Your program might be large, with dozens of instrument spread across the globe, or small with one or two instruments in a single location. These, and everything in between, have many common requirements that can be met with the appropriate set of calibrated color reference standards.

Surface Properties

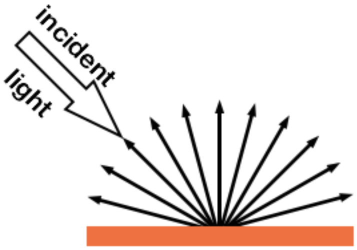
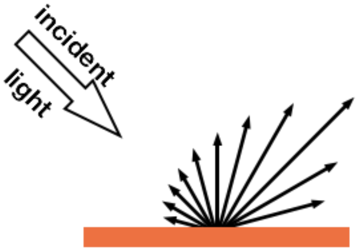
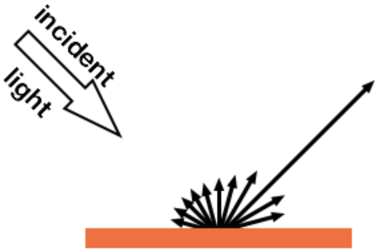
Along with color, surface properties are the most obvious visible feature of a standard. A surface can range from highly glossy to completely matte. When viewing a standard, it is easy to make a general judgement: Can I see my reflection in it? Can I see a light source, but perhaps not in very good focus? Or do I just see a uniform color, regardless of the orientation of the standard? The images below show three example orange standards, very matte (left), mid gloss (middle), and high gloss (right). Each picture was taken with the fluorescent ceiling fixture in view. The matte standard completely diffuse the image. The high-gloss standard even shows the texture in the fixture diffuser. The middle image is in between in terms of detail.

		
Low gloss matte standard	Mid gloss standard	High gloss standard

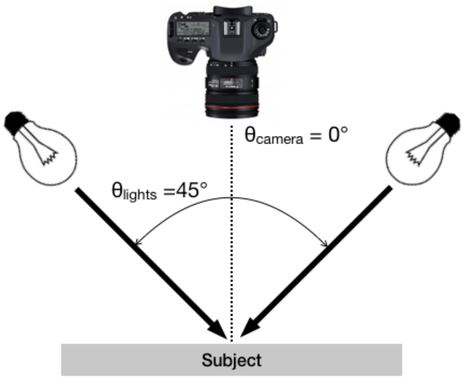
So what is going on? First let's get clear on a definition: *specular*. It comes from a Latin root meaning "mirror." So the *specular light* is that light being reflected like a mirror. We describe that as reflected light that is *equal and opposite* of the incident light. That is, the light leaves the surface at an equal and opposite angle than it is incident on the surface. We have a special name for reflected specular light: *gloss*. But that's for another day.



This distinction is important because the color of most materials is not in the specular light. So if we want to measure the color of a standard, we usually want to ignore the specular light, or at best account for it somehow. If we consider a beam of light hitting the set of orange samples, we will see that the behavior is quite different; in particular we will see that the way the light bounces off is what creates the visual (and color!) differences between the three samples. The light reflected off the low gloss sample spreads fairly uniformly across the all the angles above the surface. This shows good *diffusion*. The mid gloss standard reflects a higher percentage of light in the specular direction. Finally, the high gloss standard reflects a very high percentage of the light in the specular direction.

		
Low gloss matte standard	Mid gloss standard	High gloss standard

Why do we care about specular vs diffuse? Since the color information is in the diffusely reflected light, our instrument needs to measure the diffuse light in order to understand the color of the standard.

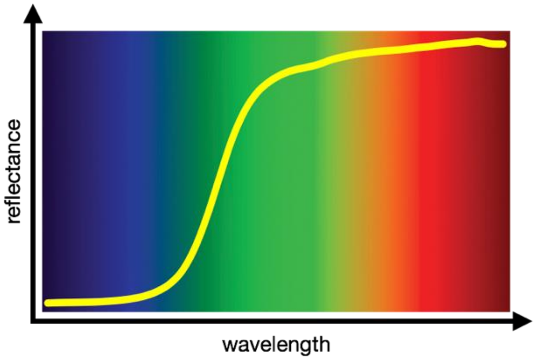


Different instrument capture the diffuse light in different ways. Your goal should be to choose a measurement method that best aligns with how your materials will eventually be viewed. For example a common photographic setup is shown at right. The lights are positioned at about 45° and the camera is perpendicular to the subject, at 0°. It you want to measure the color of the materials and have the data correlate well with this camera setup, you should choose a 45°:0° *measurement geometry*. Measurement geometry is the particular arrangement of incident light, sample, and detector in a measurement system. The notation is $\theta_{\text{incident}}:\theta_{\text{detect}}$. Note that when using 45°:0° the *specular reflection* heads right back at the other light, and does not get detected by the camera, or an instrument using the same arrangement.

If you will be using your materials outside, and the light source will be the sun and sky, then a 45°:0° measurement is not appropriate. This illumination is diffuse, incident on the sample from all directions. Fortunately, there are other instruments present the light in that fashion. These instruments are designated d:8°. The d indicates *diffuse* incident light, meaning incident from all directions. There are many more details regarding instrumentation, but again, that's for another day.

Properties of Reflectance Standards

Most modern instruments measure the reflectance of materials, and the color is calculated from that. The detailed definition of reflectance and the methods to calculate color are beyond the scope of this article. Conceptually, reflectance is the ratio of the light that reflects off an object to the light that is incident upon the object. So something that reflects lots of blue wavelengths and absorbs the green and red wavelengths will appear blue. To calculate the specific shade of blue accurately requires a mathematical transformation from the reflectance at all the visible wavelengths to color. Ultimately many industrial applications are specified by color, so the manufacturing tolerances for many things (eg: paint, plastics, fabric) are specified in terms of this calculated color. (To stay in business, we trust that this calculation correlates well with the color our customers sees.)



The figure shows a yellow line indicating the reflectance, yes, of a yellow material. We can see it has very low reflectance in the blue, and very high reflectance in the green and red. And green plus red makes yellow, right? (It does.)

When selecting the color range of your standards it is important to consider the color of samples you will be measuring. If you need a general purpose solution you need a complete range of colors. If you will only be measuring one color, say you are a large outdoor equipment manufacturer headquartered in Moline, IL, then you can save some money and just by a green reference standard.

There is a special class of colored standards that reflect all wavelengths equally. These will appear to be neutral in color; that is, white, black or some gray in between. (Yes, white and black are colors. Your art teacher used a different definition.) The image below shows a series of eight, but the number you need will depend on your application.

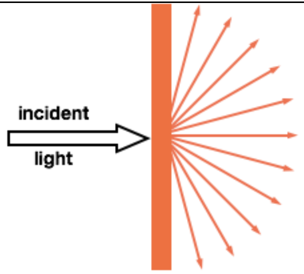
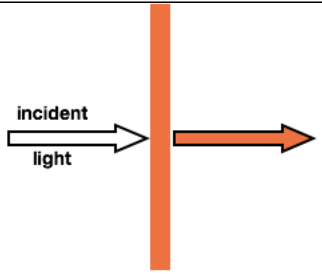
Matte or Glossy?

As introduced above, the surface properties (matte or glossy) are important aspects of reference standards. There are two main considerations with respect to the surface properties: what are the properties of your typical samples? and what are the physical conditions where you will use your standards. The first one makes good sense in from a metrological point of view; to the best of our ability, standards should be as similar to samples as can be managed practically. Meaning that is all you will ever measure is very matte blue samples, then you will get the best measurement results if your reference standards are matte and blue. Few measurement programs are so limited though, but many applications may be exclusively matte or glossy and your reference standards can reflect those qualities. (See what I did there?)

Even if you always measure matte samples, there is one consideration regarding matte reference standards: the rough matte surface can collect dirt and other contaminants. High quality reference standards can usually be cleaned, even in ways that will not affect their reflectance and color properties. But all things being equal, glossy materials are much easier to clean than matte materials.

Properties of Transmittance Standards

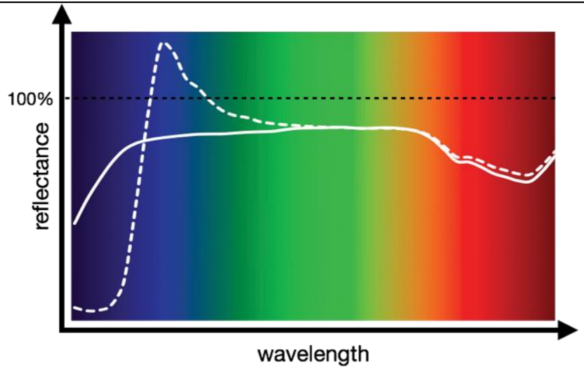
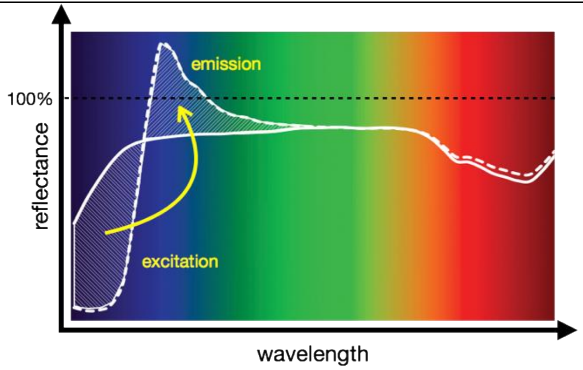
In addition to the description of reflectance, transmittance standards can be either scattering or non-scattering. These are sort of equivalent to matte and glossy, as you can see by the diagrams below. The scattering sample diffuse the light as is passes through, and the transmitted light is spread out in all directions. The non-scattering material does not change the direction of the light. Just like for the reflectance standards, the type of instrumentation you use should be able to handle the type of samples you intend on using.

	
High scattering	Non-scattering

Properties of Fluorescent Standards

For many applications, you must measure fluorescent materials. These include printing paper, fabrics, and more. Just like the colored standards, you should try to select fluorescent standards that are similar to the materials you will need to measure. Fluorescent standards are a little bit trickier though. A little science will help here.

The left figure below shows the reflectance of two white acrylic tiles. The solid line is a non-fluorescent tile; the dashed line is an identical tile with a fluorescent doping additive. The first indication of fluorescence is that the dashed reflectance curve exceeds 100%. In the right figure below, the effect of the fluorescence can be seen by the reduced reflectance in the dashed curve in the blue. The non-fluorescent tile reflects that energy, as seen by its higher reflectance in the blue region. The fluorescent compound absorbs the energy in the blue and near UV (the “excitation region”) and re-emits it in the mid-blue (the “emission region”), as shown by the peak of the dashed curve, which exceeds 100%.

	
Solid line is the reflectance of a white non-fluorescent acrylic tile. The dashed line is that of a fluorescent tile.	The fluorescent doping additive absorbs the light in the excitation range and emits radiation at a longer wavelength.

The light source in instrument used for these reflectance measurements must be carefully controlled. The strength of the UV component of that light source (about 350-400nm) can have a dramatic effect on the fluorescent emission. The result of this is that two instruments could both be functioning perfectly as designed, and yet they would make completely different reflectance measurements of the fluorescent tile shown in the above figure.

Materials That Might Cause Problems

Most regular materials should measure correctly on most commercial spectrophotometers. As discussed above, these materials (the technical term is *dielectrics*) color in the diffuse component. The specular component is always the same color as the light source. However, with metallic the situation is reversed: the color is in the specular component only. This is why most metals appear neutral – the diffuse component is the color of the light source, which is usually neutral by definition.

Other “problem” measurements:

- Translucent materials spread light laterally. So rather than staying briefly near the surface and then get reflected back, light scatters throughout the internal structure of translucent materials. This can cause some light to enter into the material, and spread laterally until it is outside of the view of the instrument, resulting in photons that get “lost” to the measurement. Thus the measurements of these materials are often lower than they might appear visually.
- Retroreflective materials reflect color mostly back in the direction of the incident light. Like metallic, they do not reflect color in the diffuse reflectance, and so will not be correctly measured by traditional instrumentation.
- Fluorescent and luminescent (“glow in the dark”) materials present difficulties as described above. Luminescent materials present the additional complication that they require time to “charge up” and then usually much longer time to give off that saved up energy. Traditional instrumentation cannot account for these effects.
- Pearlescent and effects pigments change color as a function of the angle of incident and detected light. So while you can measure these on your traditional 45°:0° or d:0° instrument, that measurement will not tell the whole story. To fully specify the color of such materials you will need a *goniospectrophotometer*, which can measure at a variety of incident and detection angles. But again, a complete description of goniospectrophotometry is for another day.

It is important to understand the instrument manufacturers know about all of these effects, and in some cases have specialized instrumentation to measure the color of material with these exotic properties. Again though, traditional color measurement instrumentation will usually fail, sometimes catastrophically, on these materials.

Summary: What makes a good Standard?

When you are paying good money for a reference standard, you want to know that they are going to last. And in this case “last” means that the important measured properties are stable over time.

Another thing we want is *robustness*. Depending on your application, color standards may have to put up with dust or dirt, temperature swings, moisture or high humidity, rough handling, and maybe more. If you must subject your reference standards to harsh or even moderately challenging conditions, consider having them recalibrated more frequently.

For most applications, robust and stable reference standards are available. If you treat them well, they will treat you well for years to come.

Questions you to answer when you want to purchase color standards

1. What will you be using your standards for?
2. Do you use an instrument now? What is the measurement geometry, or at least the make and model?
3. What type of samples do you measure? Matte or glossy? Fluorescent materials? Other?
4. What environment will you be using your standards?

Annotated Bibliography

- *The Physics and Chemistry of Color: The Fifteen Causes of Color, 2nd Edition,* Kurt Nassau*, Wiley (*2001).

  This is a good reference, but slightly dated in terms of technologies covered.

- *Reflectance Spectroscopy: Principles, Methods, Applications*, Gustav Kortüm (Translated from the German by James E. Lohr, Springer-Verlag New York (1969).

  This is a hardcore mathematical description of reflectance. If you are going to design a spectrophotometer, this is a good reference. For most everyone else, just move long.

- *The Optics of Life: A Biologist's Guide to Light in Nature,* Sönke Johnson, Princeton University Press (2012).

  An entertaining and readable book for anyone with a little science background.

- *Colour and the Optical Properties of Materials, Second Edition*, Richard J.D. Tilley, Wiley (2011).

  A comprehensive study on materials and light, and how they interact to make color.

- *Billmeyer and Saltzman's Principles of Color Technology, 3rd Edition, Roy S. Berns, Wiley-Interscience (2000).*

  A thorough study of color and color technology. It will help if you have a little science and math background, but this text is quite approachable and readable.

Do you know of a reference that should be listed here? Let us know!