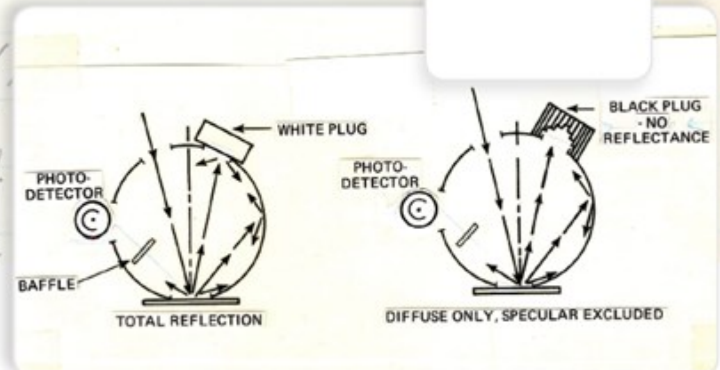
Applications Note

AN 1096



Instrument Geometries and Color Measurement

.

When deciding which geometry best fits your application, one needs to determine if the goal is to evaluate the appearance of a color or to evaluate the true color of a sample.

Abstract

In a description of instrument geometry, the first number is the angle or method of illumination and the second number is the angle or method of viewing. These are both relative to the perpendicular to the surface of the sample being measured. There are two types of instruments—one is 0°/45° or 45°/0° and the other is diffuse/8° or 8°/d. An instrument with 45°/0° type geometry illuminates an object from a 45-degree angle and detects the reflected light at 0 degrees. Diffuse illumination uses an integrating sphere to illuminate an object uniformly from all directions.

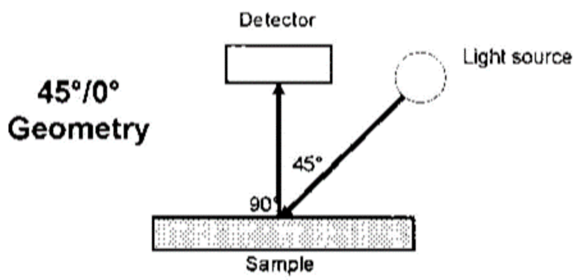
The world's true measure of color

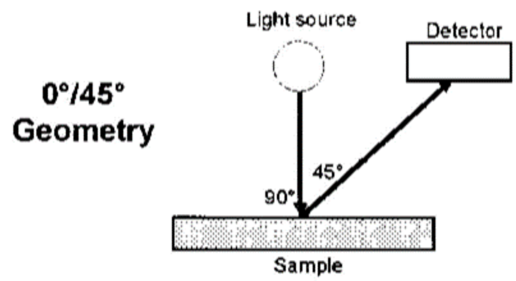
HunterLab

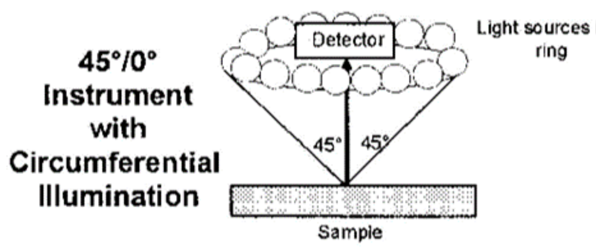
Instrument Geometry : *45°/0° and 0°/45°*

The following instruments are built using this geometry: ColorFlex EZ, MiniScan EZ, and Agera.

These instruments can have either circumferential illumination or detection. Circumferential instruments illuminate the sample using many lights in a ring around the sample, 45° from it. See the diagrams below. Measurements using the two types of instruments are slightly different, since circumferential illumination reduces the effects of sample directionality (by providing even lighting across the sample surface). HunterLab ColorFlex EZ and MiniScan EZ instruments use circumferential illumination. The Agera 0°/45° has circumferential *viewing*.







45°/0° and 0°/45° instruments measure in reflectance-specular-excluded mode only. They optimally measure *appearance* of samples, which includes a color component and a geometric component (gloss and texture). For instance, when a shiny specimen is viewed, it may appear darker and more saturated in color than a matte sample, even if the samples are equally pigmented. A 45°/0° or 0°/45° instrument yields values indicating that the shiny sample *is* darker and more saturated.

Applications

- These instruments "see" color in the same way the eye does and are preferable for applications where this feature is important.
- Measurements for which reflectance-specular excluded mode is preferred.
- For measuring differences in *appearance* of samples, including the effects of color, gloss, and texture.
- 45°/0° and 0°/45° instruments are generally preferred for measuring fluorescent samples and translucent samples by reflection.
- Opaque specimens.
- Color formulation. You should perform color formulation using samples and standards on the same substrate.
- Quality assurance/quality control.

How the Numbers Look: 45°/0° and 0°/45°

In order to demonstrate that 45°/0° and 0°/45° instruments measure how specimens appear, including the contributions of color and geometry, readings of shiny (silky) and matte cloth of the same color were made. On visual assessment, the shiny fabric looked darker and more saturated than the matte fabric. Two measurements of each fabric were made using an Agera.

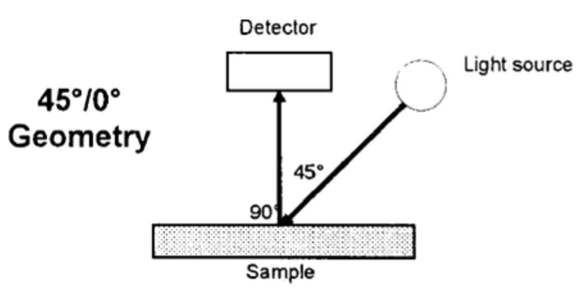
Fabric ID	L (D65/10°)	a (D65/10°)	b (D65/10°)
Shiny 1	83.92	10.63	10.98
Shiny 2	84.25	10.45	10.98
Matte 1	85.32	8.74	9.79
Matte 2	85.28	8.86	9.99
Range	1.40	1.89	1.19

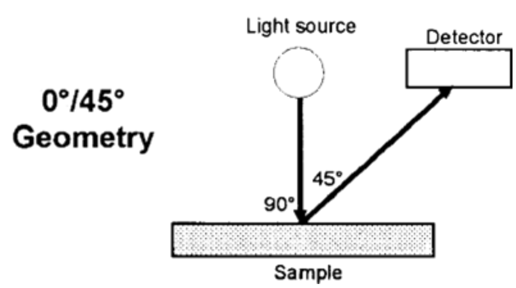
These numbers agree with the visual assessment. The shiny samples appear darker and have lower (closer to black) L values. Both a and b are larger (more saturated) for the shiny fabric.

Understanding Reciprocal Geometries

The Helmholtz Reciprocal Relation defines this principal of inverse equivalency such that if you swap the positions of the light source and detector, everything else being equal, the measured values should be the same. That is, a 45°/0° instrument is equivalent to a 0°/45° instrument for reflectance measurements. A diffuse/8° instrument is equivalent to an 8°/diffuse instrument for reflectance and transmittance measurements.

The geometry of a color measurement instrument is defined by the relative arrangement of the light source, sample plane, and detector positions. A line perpendicular to the sample plane is the reference for 0°. The geometry is described by first indicating the angle of illumination by the light source, and then the angle of viewing by the detector in a format such as 45°/0° or diffuse/8°. (See the *Applications Notes* titled "Instrument Geometries and Color Measurements.") However, when the geometry is the inverse (such as 45° *viewing* and 0° *illumination*, or 0°/45°, like HunterLab's LabScan XE), it is considered to be equivalent, as long as the illumination and viewing angles are exactly reversed.



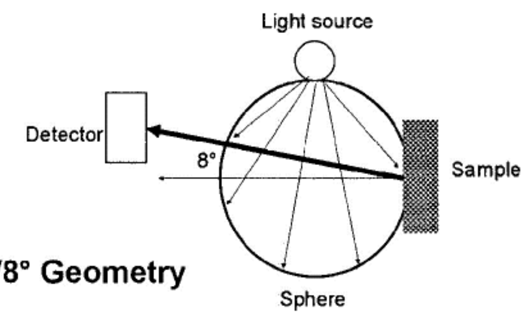


A couple of caveats:

- The condition of "everything else being equal" rarely exists when we're talking about two different instrument types or brands. Usually some element in the optical path (area of view, sphere diameter, light collection angles, etc.) is different between instruments with inverse geometries.
- Although the Helmholtz Relation holds in most applications, in its most strict sense, reciprocity of inverse geometries yielding equivalent results assumes that the sample is a flat, uniform, non-fluorescent, opaque or transparent solid—in other words, a tile or a piece of glass—and the sample must have a regular scattering pattern. The relation seldom holds for samples that exhibit irregular scattering patterns, such as translucent samples (like plastic plaques) or samples that trap light (such as loose fibers or plastic pellets), or others with extreme non-uniform characteristics like curvature. Reciprocity exceptions also include gonioapparent samples (metallic, pearlescent, interference coatings, plastics, and cosmetics) where the reflectance and corresponding color values change with the angle of view.

Instrument Geometry: Diffuse/8°

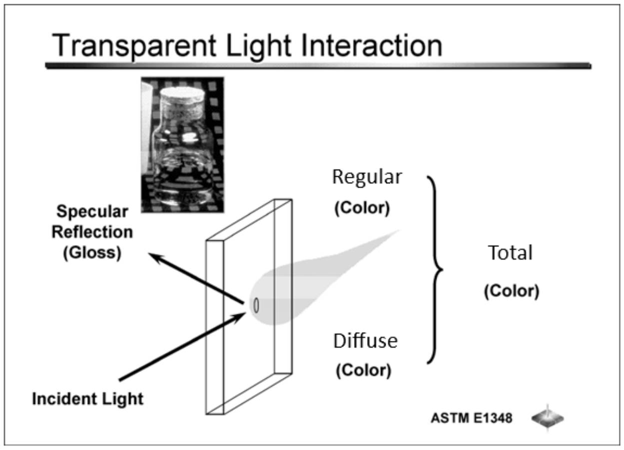
Diffuse illumination illuminates an object from all directions and detects the reflect light at an 8-degree angle. The following HunterLab instruments are built using this geometry: MiniScan EZ Diffuse, UltraScan PRO, and UltraScan VIS.



Diffuse/8° Geometry

All sphere instruments are able to measure transmittance and some have the ability to measure reflectance at a port in the sphere.

For transparent materials, color is seen primarily with **regular transmittance** that passes without deviation through the transparent material, modified by the absorption of the colorants. The presence of internal scattering centers such as scratches, cloudiness, bubbles, or suspended particles within the material or the surface texture can cause the regular transmittance signal to scatter or diffuse. This **diffuse transmittance** also contains a secondary color component of the material and is responsible for any hazy or cloudy appearance. Clear, transparent materials generally have little or no diffuse transmittance. Gloss for transparent materials is seen in specular reflectance.



Most sphere instruments are constructed in the inverse d/8° geometry (diffuse illumination/8° viewing). In this configuration, total transmittance (TTRAN), which includes both the regular and the diffuse (scattered) components of the transmitted light, is measured with the sample situated at the sphere side of the transmittance compartment. Regular transmittance (RTRAN) is measured with the sample situated at the lens, including only the transmitted light that comes straight through the sample. Diffuse transmittance is calculated as total transmittance minus regular transmittance.

Diffuse Transmittance = Total Transmittance - Regular Transmittance

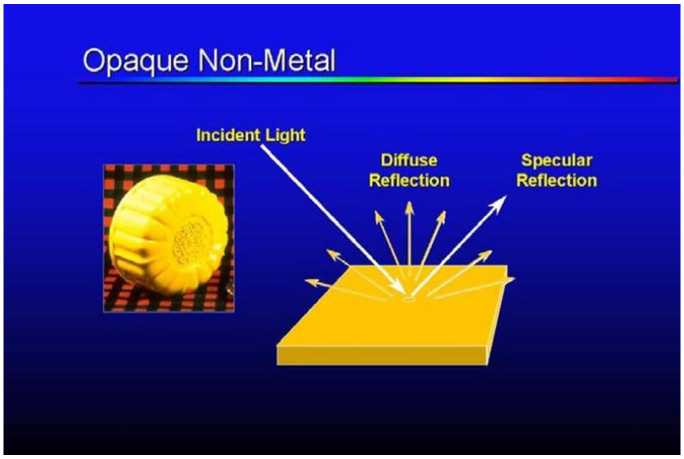
TTRAN measurements are recommended for samples that are slightly hazy and have some internal light scattering. Brewed tea, fruit juices, and biopharma/chemical solutions are examples of samples that require TTRAN measurements due to scattering. RTRAN measurements are used for clear (non-hazy, non-scattering) samples.

The 8° viewing variance from the normal allows some of the instruments (UltraScan PRO and UltraScan VIS) to measure reflectance in either specular-included or specular-excluded mode. The specular-included mode measures *total* reflectance, including diffuse reflectance (color) and specular-reflectance (direct reflectance of the light beam in an equal, but opposite, direction; mirror-like reflection or highlight). These two types of reflectance are illustrated next.

So, when should RSIN mode be used and when should RSEX mode be used?

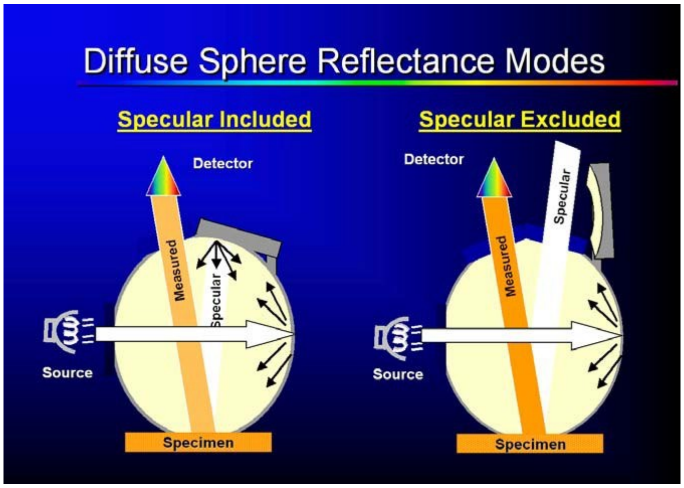
In general, brightened bare metals should be measured in RSIN mode, since their color is seen primarily in the specular reflection. If your sample is not a shiny metal, though, the answer to the RSIN versus RSEX question depends on the answer to another question: *Do you want your measurements to measure color as an actual physical property (as if to determine the exact amount of pigment used), or do you want to measure specimen appearance (that is, what it looks like to a human being)?* Consider a sample of a single color of plastic or paint with areas that differ only in surface texture, as in the picture.

The specular-excluded mode measures diffuse reflectance only. The specular component is excluded by opening the section of the sphere from which light would ordinarily be specularly reflected from the sample to the detector. For the UltraScan VIS and UltraScan PRO this is done using a motorized specular-included/excluded port door that opens or closes the appropriate section of sphere as needed. The instrument configurations for a sphere instrument with the sphere port door closed and open are shown in the next figure.



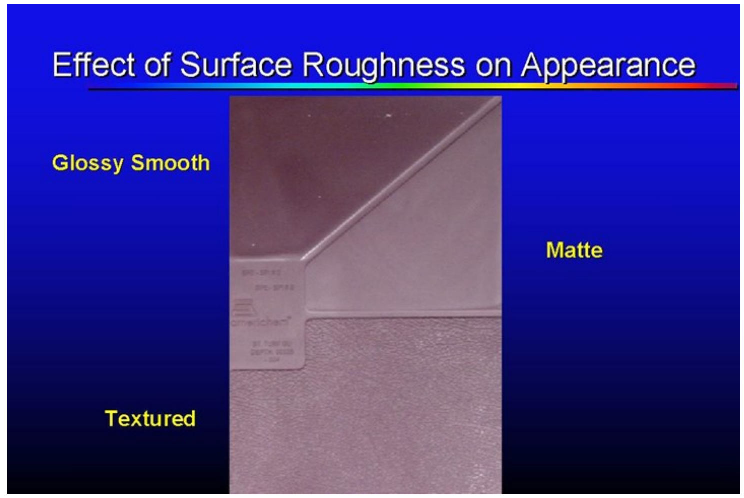
Inside of the transmittance compartment of the UltraScan looks like the photos below:

Note that specular-exclusion is not complete in sphere instruments, so different models may yield different results in specular -excluded mode. This difference is particularly noticeable for dark, glossy samples.



Specular Port Closed (RSIN)

Specular Port Open (RSEX)



The color is constant throughout the three areas, as previously mentioned. However, the surface texture makes them *appear* differently to the eye. The glossy smooth area appears darker and more saturated than the matte and textured areas.

If the three areas are measured on a sphere instrument in RSEX mode, which approximates the way the glossy surface would ordinarily be viewed visually, the appearance difference would be shown by the instrumental measurements. If, on the other hand, the areas were measured in RSIN mode, measuring all the light the sample reflects, the values would indicate that the color is indeed the same across the three areas.

As an illustration, a single paint chip with both a glossy surface and a matte surface was measured in RSIN and RSEX modes on an UltraScan. As you can see from the table below, in RSEX mode, the difference between the two surfaces was readily apparent (DEcmc is 2.75), but not significant in RSIN mode (DEcmc of 0.21).

RSIN					**RSEX**				
	L*	**a***	**b***			**L***	**a***	**b***	
Glossy standard	32.97	19.24	5.17		Glossy standard	25.00	25.84	7.68	
	dL*	**da***	**db***	**dEcmc**		**dL***	**da***	**db***	**dEcmc**
Matte sample	0.24	-0.01	-0.16	0.21	Matte sample	3.08	-2.76	-1.44	2.75

Therefore, if you want your instrument to measure **appearance** and **appearance difference** as seen by the eye, taking into account the effects of texture and finish, you would want to measure in **RSEX** mode. If you were concerned with the **actual color content** or doing **color formulation**, you would want to use **RSIN** mode.

Applications

- Color formulation.
- Measurements for which choice of reflectance mode is important.
- Transmittance measurements of translucent and transparent materials, and for haze measurements (Vista, UltraScan PRO, and UltraScan VIS only).
- Color of brightened bare metals by reflection with specular component included.
- Color matching to a standard of different surface texture.
- Color quality assurance of opaque specimens.

Instrument Geometry: 45°/0° and Diffuse/8° Comparison of Absolute Measurements

45°/0° (or 0°/45°) and sphere instruments generally do not give identical absolute results for reflectance measurements. This makes sense when we remember that 45°/0° and 0°/45° instruments measure diffuse reflectance of samples, providing results that agree with visual assessments made with similar illumination and viewing conditions. The usual mode for sphere instruments is reflectance-specular included (diffuse plus specular reflectance). The measurements obtained for a single green tile using an UltraScan PRO sphere instrument in RSIN and RSEX modes were compared to those obtained from an Agera as shown in the table below. Two readings were made for each instrument mode and averaged.

As you can see, the numbers are in the same ballpark, but are not close enough to meet the specifications of most companies. It is always advisable to compare absolute measurements only from instruments of the *same geometry*. Preferably, these instruments would also be of the same brand and model so that inner dimensions and other instrument specifications would not cause the readings to differ. If this is not possible, however, difference measurements can be compared more reliably than absolute measurements.

Difference Measurements

When used to measure color differences between items that are **equal in gloss and surface texture**, the two types of instruments will give very similar or equal results. An illustration is provided in the table below. Two green paint chips of equal gloss and texture were measured on an UltraScan PRO (in RSIN mode) and an Agera. The first chip (Chip 1) was measured as a standard (twice), and the second chip (Chip 2) was measured as a sample. The difference data is provided in the next table.

Sphere RSIN	L D65/10°	a D65/10°	b D65/10°	Sphere RSEX	L D65/10°	a D65/10°	b D65/10°	0°/45° TD	L D65/10°	a D65/10°	b D65/10°
Read 1	49.30	-16.33	7.82	Read 1	43.77	-18.24	8.92	Read 1	44.99	-18.79	9.60
Read 2	49.31	-16.34	7.83	Read 2	43.77	-18.23	8.92	Read 2	44.97	-18.77	9.60
Avg	49.31	-16.34	7.83	Avg	43.77	-18.24	8.92	Avg	44.98	-18.78	9.60
Difference between sphere RSIN values and 0°/45° values									**4.33**	**2.44**	**-1.77**
Difference between sphere RSEX values and 0°/45° values									**-1.22**	**0.54**	**-0.68**

When comparing measurements made on instruments of different geometries, it is best to compare difference values rather than expect absolute values to correspond.

Sphere	dL* (D65/10°	da* (D65/10°	db* (D65/10°	45°/0°	dL* (D65/10°	da* (D65/10°	db* (D65/10°
Reading 1	-0.77	0.19	-0.23	Reading 1	-0.98	0.15	-0.17
Reading 2	-0.78	0.19	-0.22	Reading 2	-0.96	0.19	-0.24
Average	-0.78	0.19	-0.23	Average	-0.97	0.17	-0.21
Difference between sphere values and 45°/0° values					**0.21**	**0.02**	**0.02**

References

Hunter, Richard S. and Harold, Richard W., *The Measurement of Appearance*, New York: John Wiley & Sons, Inc., 1987.

Clarke, F. J. J. and Parry, D. J., "Helmholtz Reciprocity: Its Validity and Application to Reflectometry," *Lighting Research and Technology*, Volume 17: 1985, pp. 1-11 is a key document that describes the application of Helmholtz Reciprocity to spectrophotometers.

CIE Publication 15:2004, *Colorimetry*, Section 5.2 provides a list of all the recommended instrument geometries for colorimetry, including inverse geometries.

ASTM E179, "Standard Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials," Section 8.2 calls the equivalency of reciprocal geometries the Helmholtz Reciprocal Relation.

ASTM E1164, "Standard Practice for Obtaining Data for Object-Color Evaluation," describes the inverse reflectance and transmittance geometries in Section 8.

ASTM E1767, "Standard Practice for Specifying the Geometry of Observations and Measurements to Characterize the Appearance of Materials," is a key document that defines instrument geometry precisely in terms of the azimuthal angle and includes inverse geometries.

ISO 5-2, *Photography -- Density measurements*, Part 2: "Geometric conditions for transmission density."

ISO 5-4, *Photography -- Density measurements*, Part 4: "Geometric conditions for reflection density."

Berns, Roy S., *Billmeyer and Saltzman's Principles of Color Technology*, 3rd Edition, John Wiley & Sons: New York (2000:82-88) provides a good overview of reciprocal instrument geometries for colorimetry, and references inverse geometries.

About HunterLab

HunterLab is the technology leader in color measurement solutions, providing instruments, software, knowledge and service to a wide variety of industries.
With over 5 decades of experience in more than 65 countries, HunterLab applies our leading edge technology to your products helping you measure and communicate color simply and effectively.

 1/2024

The world's true measure of color
HunterLab