Fundamentals of Color and Appearance

Module 8

Instrument Geometry

Color Science Educational Series

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Fundamentals of Color and Appearance

Module 8:

Instrument Geometry

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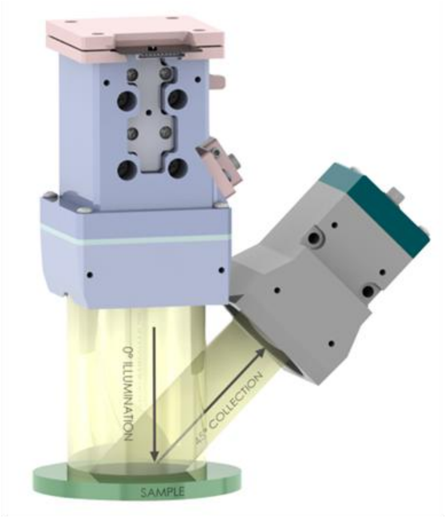
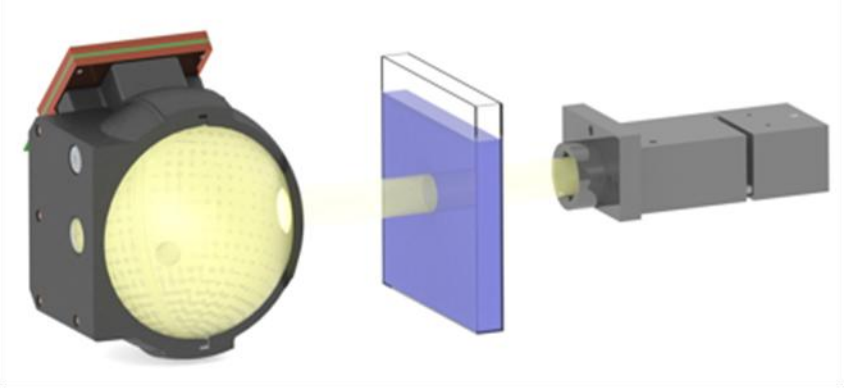
Instrument geometry refers to the spatial arrangement between the light source, the sample, and the detector in a color measurement instrument. There are two primary categories of geometries: directional and diffuse. The selection of geometry is largely determined by the physical characteristics of the sample being measured and the application needs.



Directional (Reflectance) Geometry



Diffuse (sphere) Geometry

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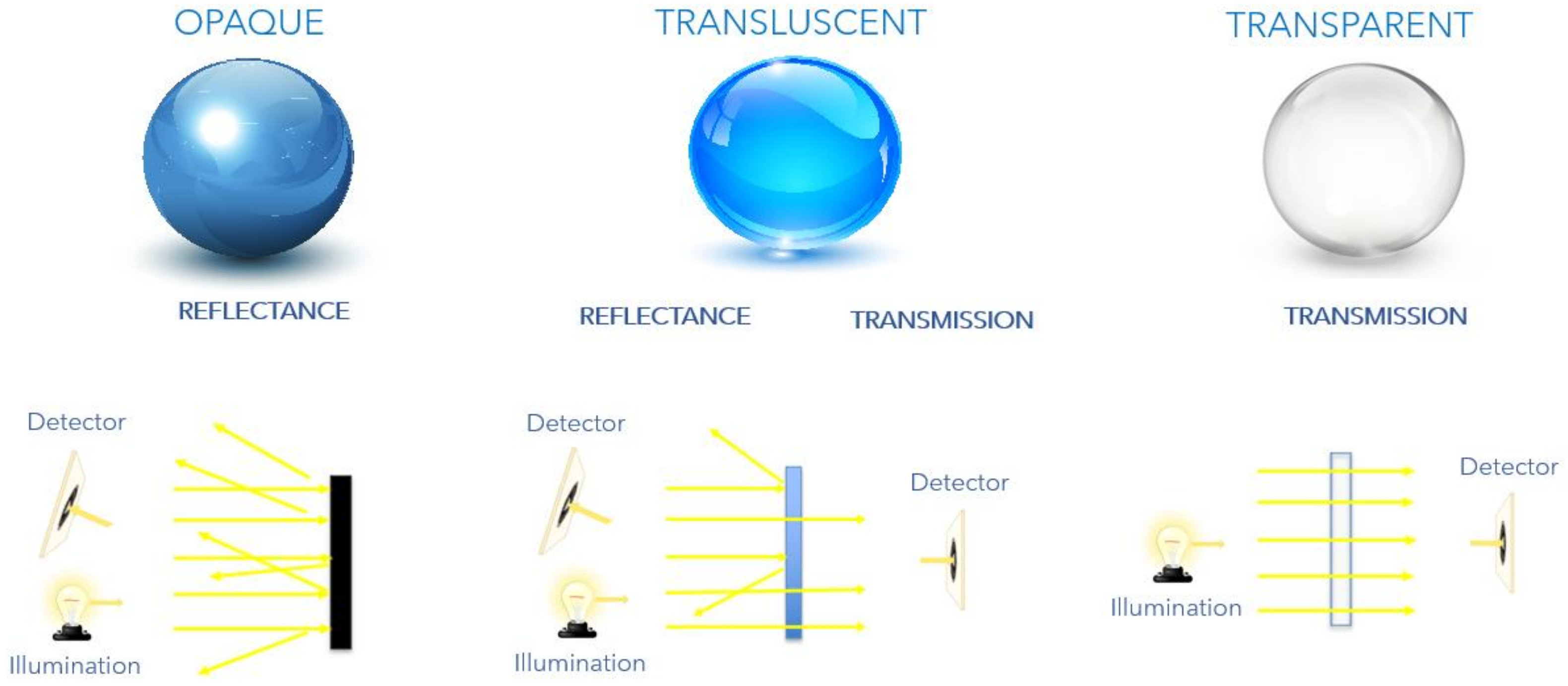
As discussed in Module 3, samples can range from fully opaque to fully transparent or fall somewhere in between.



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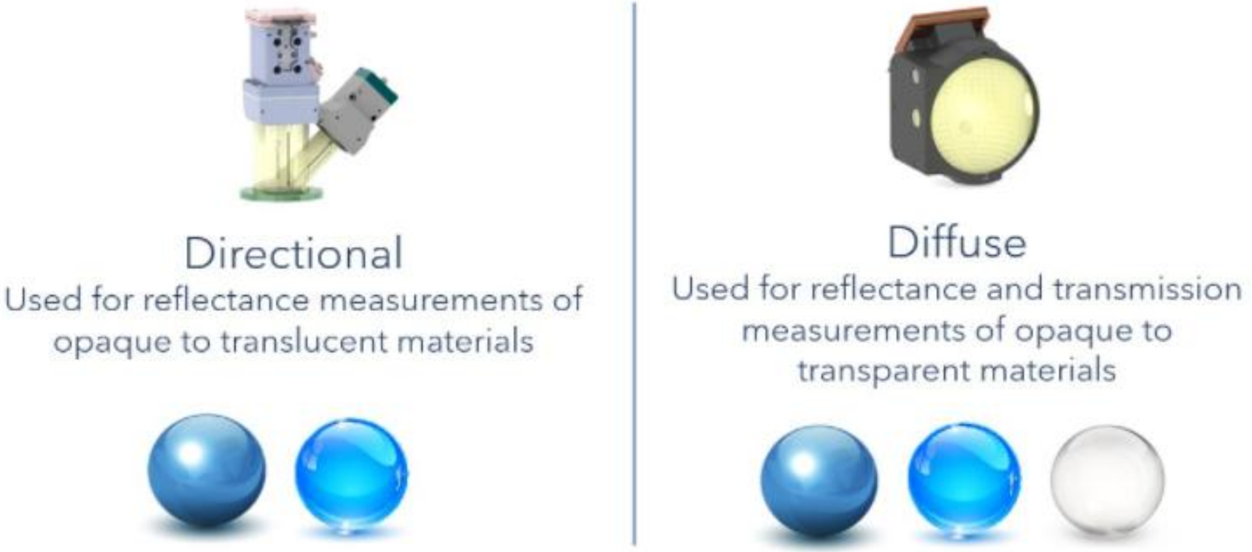
Instrument Geometry

Transparent samples are always measured using diffuse transmission instruments.

Opaque samples can be measured using directional reflectance or diffuse reflectance instruments.

Translucent samples, which lie between opaque and transparent, may require directional reflectance, diffuse reflectance, or diffuse transmission, depending on the transmittance of the sample and what properties are being measured.



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Directional reflectance instruments work exactly as the name suggests. They direct a controlled beam of light onto the sample surface, very much like pointing a flashlight at an object. The instrument then measures the amount and quality of light that reflects back to the instrument sensors at a specified angle.

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Instrument Geometry

Diffuse geometry, used for both reflectance and transmission measurements, illuminate the measured sample with light that has been scattered or diffused, much like a light bulb that shines light in all directions.

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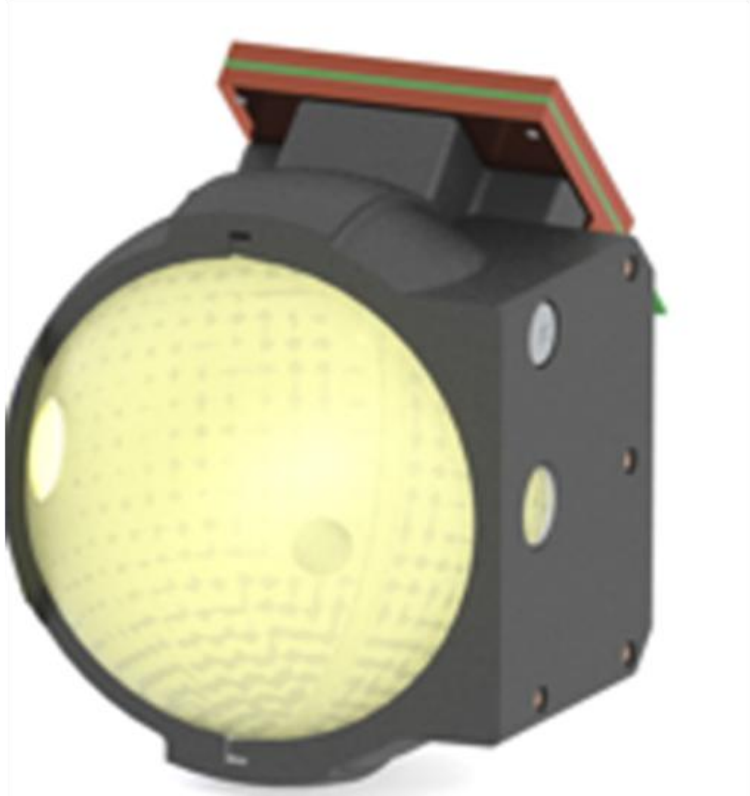
In diffuse geometry, the sample is illuminated with light that has been scattered or diffused in all directions by bouncing it around inside a coated sphere, and the detector analyzes the reflected or transmitted light from the sample, typically at 0 degrees for transmission measurements and 8 degrees for reflectance measurements.

Diffuse sphere Geometry



Whether you are measuring the reflected color of opaque materials…

Or measuring transmitted color of transparent solids or liquids…

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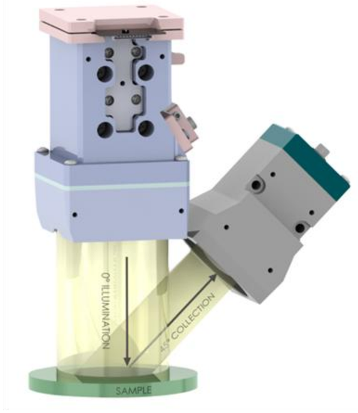
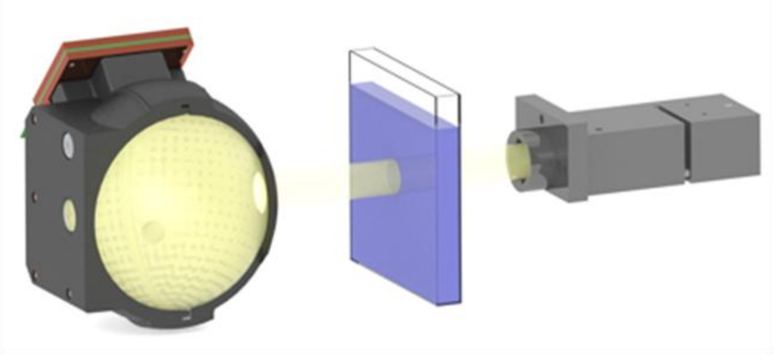
Understanding these geometry differences is essential when selecting the correct instrument for your samples, because directional and diffuse instruments interact with materials differently, and can produce different measurement results.



Directional (Reflectance) Geometry



Diffuse (sphere) Geometry

Let's begin by distinguishing between **specular included (SPIN)** and **specular excluded** (SPEX) in both visual perception and color measurement.

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Instrument Geometry

Specular included captures the combined effect of a material's surface characteristics–such as gloss, smoothness, and texture–along with its intrinsic color.

Specular excluded, by contrast, isolates the true color of the material, minimizing the influence of surface shine or glare. We will come back to this image in a moment.

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Humans naturally perceive color in a **specular excluded** way, since we tend to look past glare to focus on the underlying color.

Specular included, on the other hand, appears to us as the bright white highlight we see when light reflects directly from a shiny surface into our eyes.

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In this example, we can see just how surface texture and gloss can distort our perception of color.

Although the sample is uniformly colored, one side is molded in different textures and gloss levels. Due to the way light scatters differently across these surfaces, our eyes perceive them as different colors, even though they are the same.

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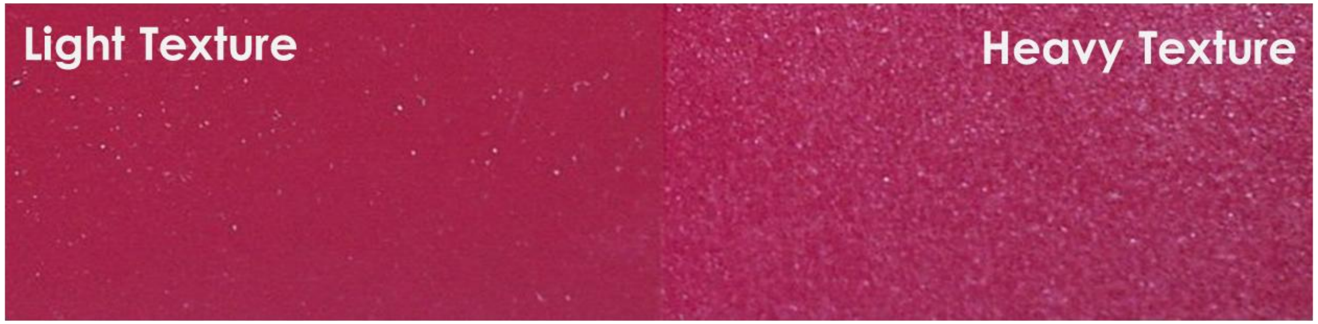
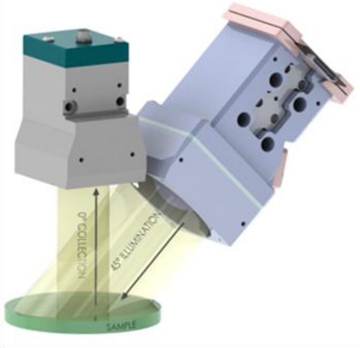
When measured using directional reflectance, the color between the light texture and the heavy texture shows significant differences in delta L, delta a and delta b, even though the colors are actually the same. This is due to how light reflects back to the instrument, capturing the full color appearance, including both the inherent color and the influence of surface characteristics such as texture and gloss. This replicates how the human eye see's color.

Directional 0°/45° Geometry





	ΔL*	Δa*	Δb*
Specular Excluded	1.4	-1.5	-1.2

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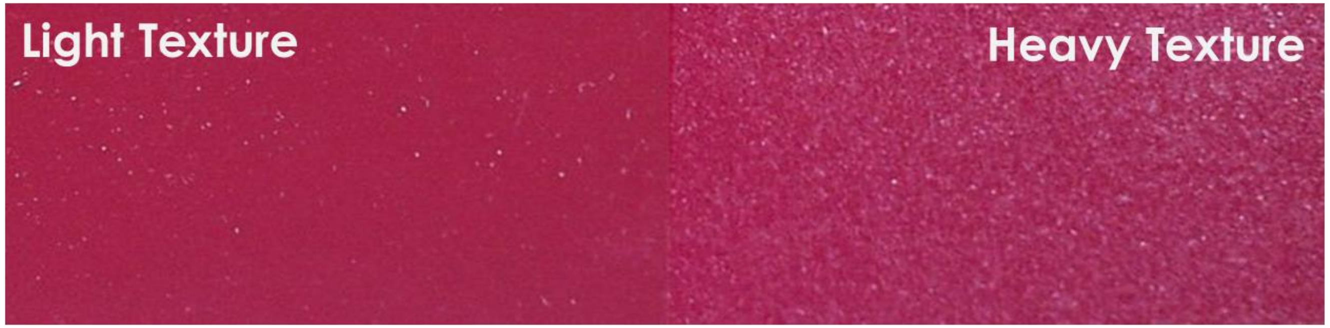
Instrument Geometry

When comparing this to measurements taken with a sphere reflectance instrument operating in specular included mode, both sides of the sample appear as the same color, with differences in L, a, and b values effectively zero. This is because in specular included mode, the measurement captures only the color of the sample, ignoring the effects of surface texture or gloss.

Sphere Geometry d/8°



	ΔL^*	Δa^*	Δb^*
Specular Included	0.0	0.1	-0.0

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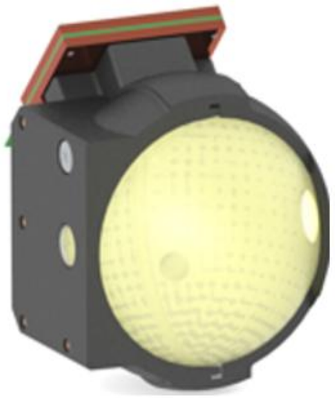
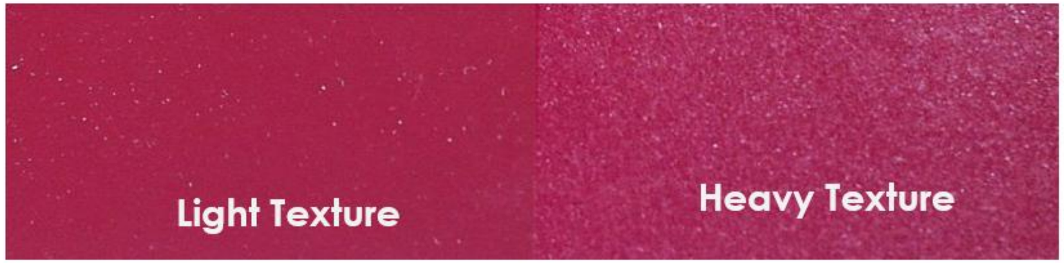
Now let's compare diffuse specular included and diffuse specular excluded modes. In this example, you can observe the clear differences between specular included and specular excluded measurements when measured using diffuse geometry. These two modes often yield significantly different results when measuring the same sample.





	ΔL*	Δa*	Δb*
Specular Included	0.0	0.1	-0.0
Specular Excluded	1.8	-1.6	-0.9

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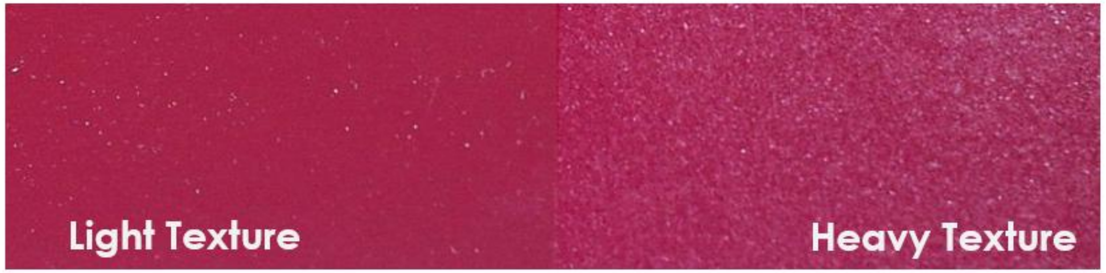
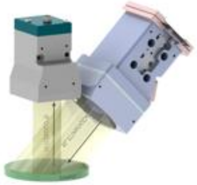
Instrument Geometry

Finally, lets compare the directional geometry measurement to the sphere specular included and specular excluded measurements. In specular excluded mode, their results do not match. This illustrates a key principle: diffuse specular included and specular excluded measurements are not interchangeable, and neither are directional and diffuse measurements.



	ΔL*	Δa*	Δb*
Specular Included	0.0	0.1	-0.0
Specular Excluded	1.8	-1.6	-0.9



	ΔL*	Δa*	Δb*
Specular Excluded	1.4	-1.5	-1.2

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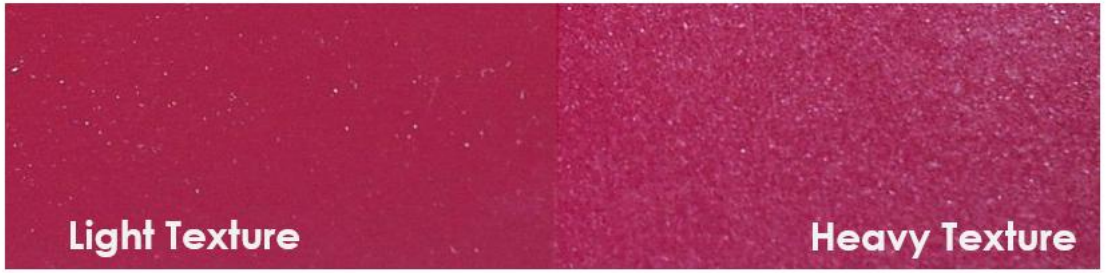
The important takeaway is this: Always standardize on a single instrument type and geometry when creating product standards and ensure that all quality control measurements are performed using that same instrument and geometry to maintain consistency and avoid incorrect conclusions.



	ΔL*	Δa*	Δb*
Specular Included	0.0	0.1	-0.0
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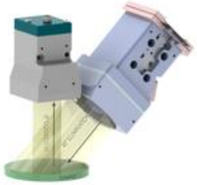

	ΔL*	Δa*	Δb*
Specular Excluded	1.4	-1.5	-1.2

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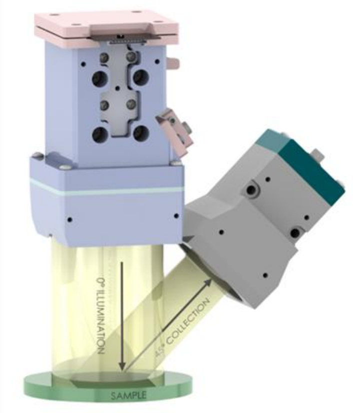
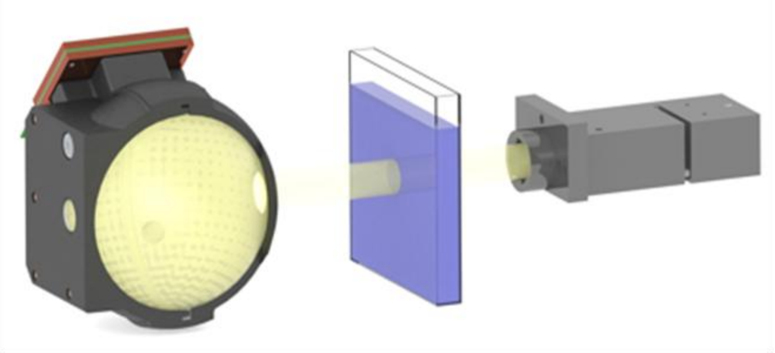
Next, let's look at the engineering behind directional and diffuse instruments and how they work.



Directional (Reflectance) Geometry



Diffuse (sphere) Geometry

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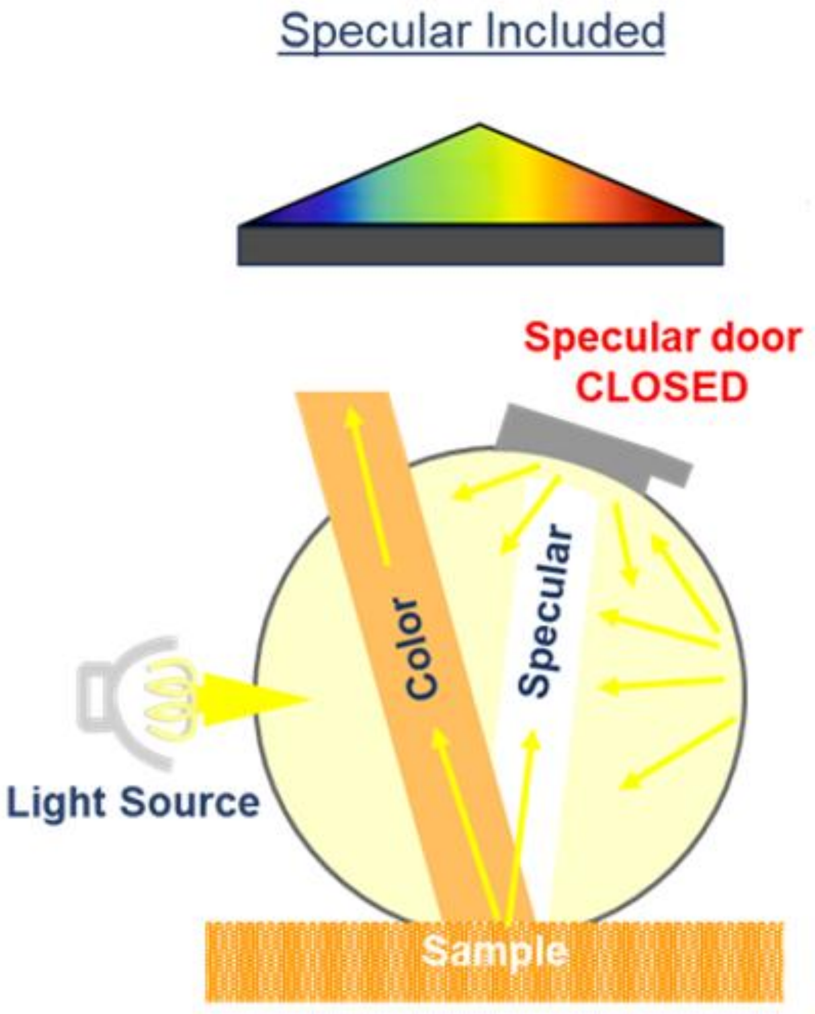

With diffuse instruments, the integrating sphere scatters light in all directions.

Here you can choose to include or exclude the specular component by using or removing a light trap.

Near the sample port, the sphere includes a specular exclusion trap—a small opening or mechanical door positioned in line with the angle of specular reflection, typically at 8 degrees.

In specular included mode, the door remains closed, allowing all reflected light—including the specular reflection—to bounce around inside the sphere and be measured by the detector.

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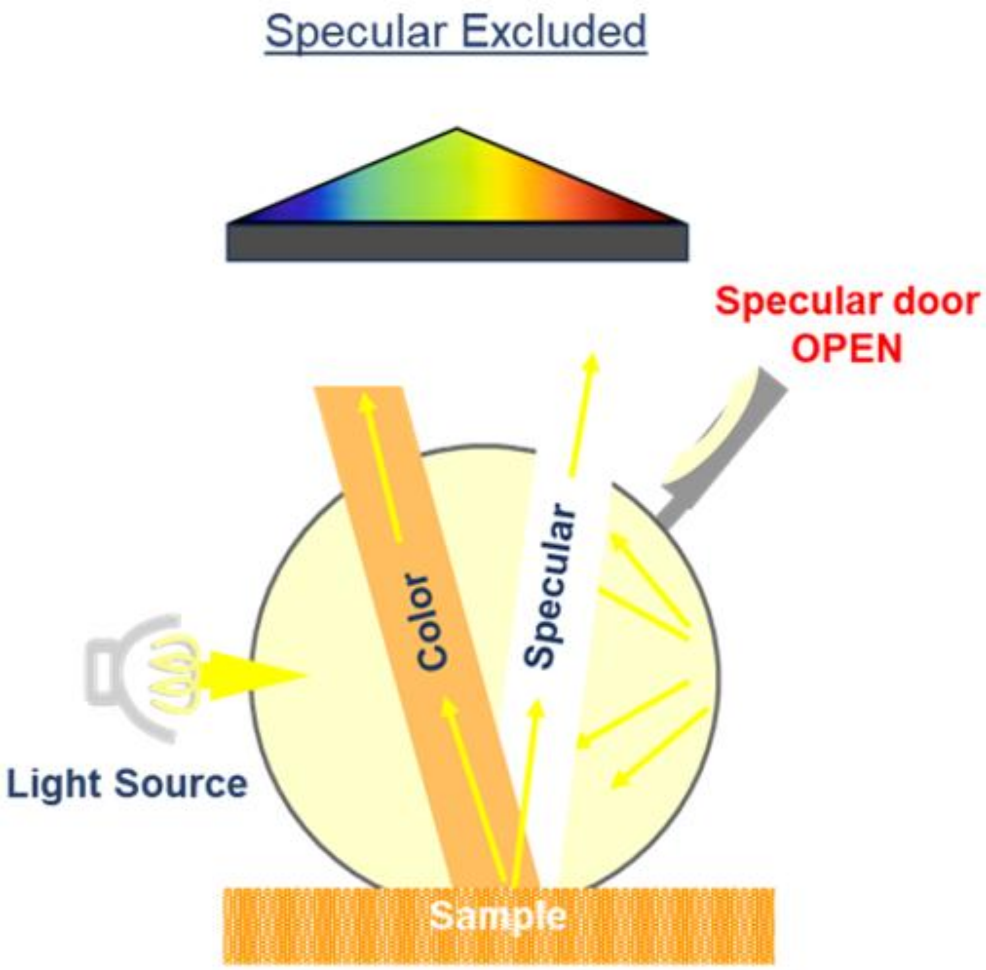

In specular excluded mode, the door opens, and the specular reflected light escapes through the trap before it reaches the detector.

This excludes gloss and surface reflection, allowing the instrument to capture appearance-based differences caused by texture, finish, or surface irregularities.

By simply opening or closing this door, the same instrument can switch between specular included and specular excluded modes, making it highly versatile for evaluating both intrinsic color and visual appearance in applications like color formulation.

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Directional 45/0° and 0/45° instruments do a better job of excluding the specular compared to diffuse sphere and replicate the human response to color.

In a directional instrument, the light strikes the sample at typically 45/0° and the detector evaluates the reflected light at 0°, or vice versa. By design, this setup avoids collecting the specular reflection, the mirror-like glare, because the glare bounces off at 45° in the opposite direction, not into the detector.

This matches how the human eye typically perceives color when we look at objects without being blinded by glare.

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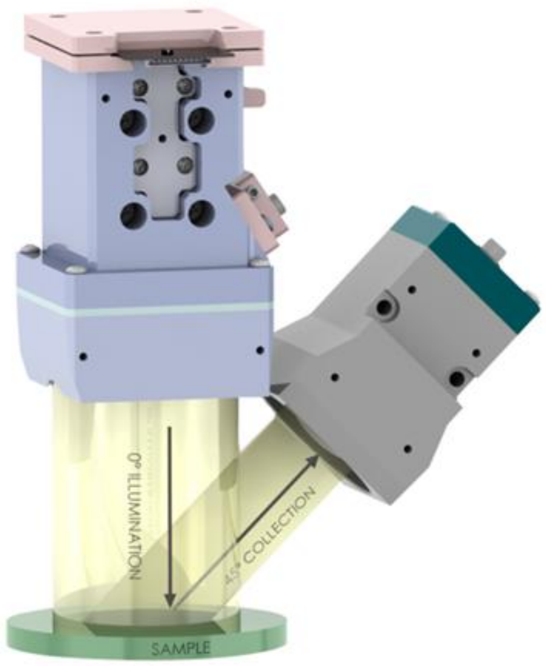
Instrument Geometry

Directional reflectance instruments come in several configurations.

Single Directional 45/0° and 0/45° geometry focuses a beam of light onto the sample at a fixed angle of either 45° or 0°, and the reflected light is collected at 0° or 45°.

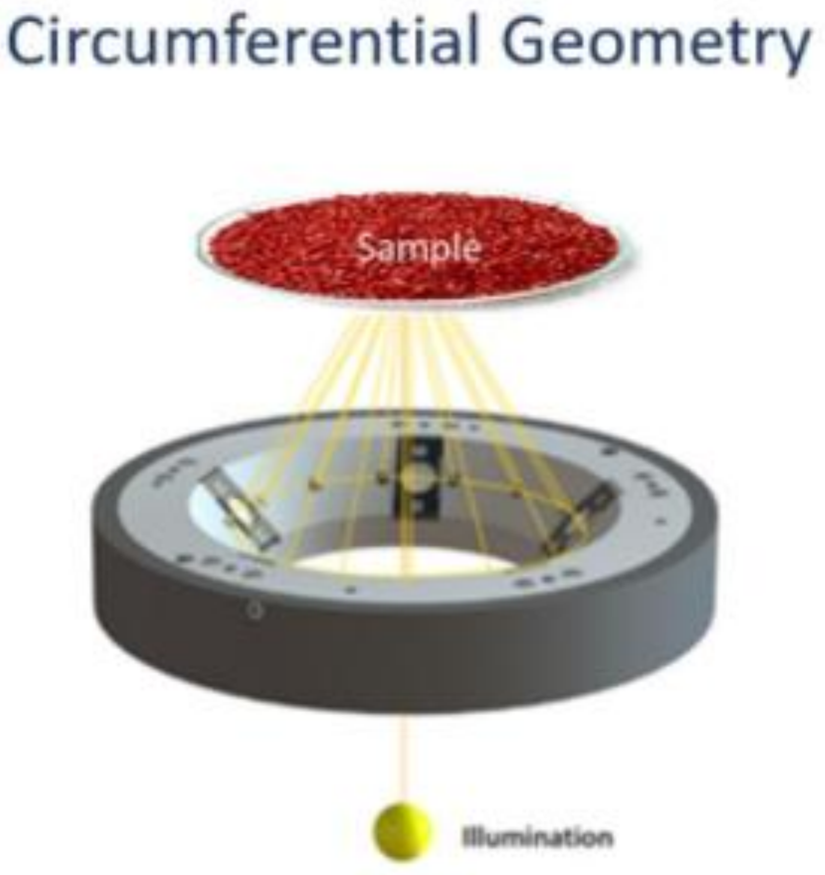
This configuration is best for smooth, non textured materials.



Directional (Reflectance) Geometry

Circumferential Geometry, or ring viewing geometry, illuminates the sample from a single fixed direction, typically at zero degrees nominal to the sample.

Reflected light is collected by sensors positioned three hundred sixty degrees around the sample, typically at a 45° angle. This is useful when the sample surface might reflect differently depending on angle, like when measuring plastic pellets, ensuring more representative measurements.



Annular Illumination, or ring illumination, illuminates the sample three hundred sixty degrees around the sample at a fixed angle, typically 45°and the detector views the reflected light at 0° degrees.

By averaging light from all directions, this reduces directional bias from surface features like grain or texture.

Annular Geometry

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And if measuring transparent and translucent solids and liquids with light transmission of 30% or more then transmission measurement using **diffuse/sphere geometry is required**, preferably with the ability to measure haze and turbidity.

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Before we conclude this module, understand that Spectrophotometric geometries are standardized by international organizations such as ASTM, ISO, and CIE to ensure consistency and comparability of color measurements worldwide. These standards define the relationship between the illumination source, the sample surface, and the detector.

By prescribing how light is delivered and collected, the standards eliminate ambiguity in measurement conditions, allowing manufacturers, suppliers, and customers to measure and communicate color values with confidence across industries and applications.

Internationally Recognized Standards

CIE — International Commission on Illumination / Commission Internationale de l'Eclairage / Internationale Beleuchtungskommission

ASTM INTERNATIONAL — Standards Worldwide

ISO — International Organization for Standardization

Always check compliance before investing

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Thank you for joining us on this journey through color science.

Be sure to watch module 9 in this series, **Haze, Turbidity, Opalescence**, to learn why measuring both color and clarity provides a more complete evaluation of product quality and appearance for transparent and translucent liquid and solid samples.

And be sure to visit **hunterlab.com** to learn more about how our solutions can help you achieve color confidence, every time, or to schedule a consultation with one of our color experts.

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Module 9

Haze, Turbidity, Opalescence

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