UNDERSTANDING
Datacolor

GLOSS
COMPENSATION

What Is Gloss?

When light strikes an object, most of the light enters the object but a small amount is reflected off the surface of the object. This surface reflected light, which is responsible for the shiny or bright appearance of an object, is the appearance attribute called gloss.

![Figure 1](image)

Figure 1 shows a beam of light of intensity \( I \) incident upon an optically smooth film. A small percentage of this light is reflected off the surface but most of the light enters the film. The reflected beam \( S \) leaves the surface at an angle \( r_1 \) which is equal to the incident angle \( i \).

The light beam \( R \) that enters the film is changed in direction or refracted upon entering the different material. This occurs because there is a difference in refractive index' between the two mediums. In the example in Figure 1, the incident beam \( I \) is in air with a refractive index of 1.00 and the object material has a refractive index of 1.50. The amount of bending of the light beam depends on the refractive indexes of the mediums and is related to the sine of the angles by Snell's Law.

\[
\frac{\sin i}{\sin r_2} = \frac{n_2}{n_1}
\]

See Appendix A for Explanation of Reflective Index.
Specular Reflection

Specular reflection refers to the mirror-like reflection of light from a smooth surface. When light strikes a perfect mirror surface, all of the incident light is reflected off the surface. The angle of the reflected light beam is equal to the angle of the incident light beam.

For objects that have optically flat surfaces but are not mirrors or metals, the specular reflectance differs in magnitude but not in direction. The amount of specular (mirror-like) reflection from a smooth surface will depend on the refractive index of the material and the angle that the light strikes the surface. The angle of the reflected light beam will still be equal to the incident light beam. A theoretical value for the specular reflection can be calculated using the Fresnel equation, which will give the specular value for any refractive index or angle of incidence. If all objects were optically smooth or flat, the measurement of specular reflection would be straightforward.

An optically smooth or flat surface is glossy in appearance. Because of the directional nature of the specular reflection, the observer can position the sample to eliminate the specular reflection from his field of view. This permits the observer to only see the light from the interior of the sample. The observer in this case sees the color with maximum saturation because the surface reflected light is not included in the view. The specular reflectance has the same chromaticity or color as the light source and since it never penetrated the surface, it dilutes the object's saturation.

An example of this observation would be a newly waxed black car. The car looks very bright and shiny but also appears very black and highly saturated. The brightness is the result of seeing the specular reflection and the saturated black is observed when we change viewing angles and eliminate the specular. We are then observing the color without any surface reflected light in our field of view.

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2 See Appendix B for Explanation of Fresnel Equation.
Diffuse Reflection

Most real objects do not have perfect mirror-like surfaces. As the surface becomes rougher, the specular reflection becomes diffuse. This means that the light is reflected back at many different angles, instead of only the mirror angle. This rough type of surface is referred to as a matte surface. The specular reflection is not reflected back at the same angle as the incident angle. Instead the reflected light is spread out over a range of angles depending on the makeup of the surface.

The viewer of a matte object cannot eliminate the surface reflection by changing the viewing angle. Because of the diffuse nature of the surface reflectance, the observer will always see some of this surface reflectance. This diffuse surface reflected light, which has the chromaticity or color of the light source, is added to the light from the interior of the object and tends to lighten and desaturate the color of the object.

An example of this observation is to take the newly waxed black car in the previous example and sand blast or abrade the surface of the car. Instead of seeing a shiny and deeply saturated black color, we would now see a duller and dark gray color. The pigmented paint layer did not change. The paint surface is now a matte finish and the specular reflection is diffuse. When we observe the car, we will always have some of the specular in our field of view, no matter what our angle of view. The car now looks lighter and less saturated than when it was newly waxed.
Specular Gloss

Specular gloss is a measurement of the brightness of the reflected image. A numerical value is determined based on the ratio of the specular reflection from a sample, to the specular reflection of a standard material, under the same geometric conditions. This numerical value is the specular gloss value and it is usually obtained from an instrument called a glossmeter.

The glossmeter consists of a light source that directs the light to the sample at a fixed angle. A light detector is placed at the mirror angle to measure the intensity of the reflected image. Figure 6 shows the physical setup of a gloss meter. The 60\(^\circ\) angle is the most commonly used angle with the 20\(^\circ\) used for high gloss materials and the 85\(^\circ\) used for low gloss or matte materials. The gloss angle should always be specified with any reading. (Note. AS7M D-523 recommends 20\(^\circ\) for 60\(^\circ\) gloss > 70 and 85\(^\circ\) for 60\(^\circ\) gloss < 10.)

![Figure 6 - Specular Glossmeter](image)

The measured reflectance is not used directly, but is compared to the light reflected from a black glass standard. The light reflected from the sample is divided by the light reflected from the standard black glass. This value multiplied by 100 is defined as specular gloss.\(^3\)

It is important to note that the specular glossmeter is measuring only specular gloss. There are other types of gloss. Two objects may have the same specular gloss but appear distinctly different to an observer. An example of this situation can be seen where one sample shows a very clear and sharp reflected image and another sample shows a blurred and hazy image. The samples may have the same specular gloss but a visual appraisal will indicate a difference.

The above is an example of distinctness-of-image gloss. Other types of gloss include contrast gloss, absence-of-bloom gloss, sheen, etc. The important point to realize is that gloss, especially as it relates to appearance, includes other aspects in addition to simple specular gloss as measured by a glossmeter.\(^1\)

\(^3\)See Appendix C for more information on Specular Gloss.
The Gloss Problem

The lack of agreement between visual and instrumental evaluations of color samples that have different gloss has been a major problem in making color appearance judgments. A human observer can easily change the viewing conditions and the viewing angles in order to make an appearance judgment, taking "into account both color and gloss simultaneously.

Color measuring instruments are not as versatile as the eye, since measurements are made at fixed illumination and viewing conditions that do not correspond to the way we see objects. The human eye has much greater resolving power than most instruments and can distinguish very small appearance differences between objects.

The basic problem encountered when viewing samples having different gloss can be illustrated in the following example. Suppose we have two black samples; one with a high gloss surface and the other with a low gloss or matte surface. If these samples are measured with an integrating sphere instrument with the specular included (type SCI d/0), the color difference will show that there is a small color difference between the matte sample and the high gloss sample. A visual assessment of these samples will indicate that there is a larger color difference. The high gloss sample will appear much darker and more saturated than the low gloss sample.

In order to understand this problem, one needs to become aware of the relationship between instrument geometry and surface reflectance. We have already seen the visual effects of objects with different surface characteristics. We will now examine the effect of instrument geometry on samples with differing gloss.
Instrument Geometry

Instrument geometry refers to the physical makeup of the color measuring instrument; relating specifically to the nature and position of the light source, and the angles of the viewing optics. The instrument geometry will greatly affect the measurement data and the color difference calculations derived from this data. There isn't one instrument geometry that can duplicate the large number of viewing conditions used in day to day color evaluations worldwide. There are, however, some standardized instruments geometries that have been defined by the CIE\(^2\) and have been used successfully for years in both color matching and quality control applications.

Standard Illuminating and Viewing Conditions\(^3\)
Specular Component Included (SCI) - d/0

This condition uses an integrating sphere to diffusely illuminate the sample and uses a viewing angle near the normal to the sample surface (i.e. perpendicular to the surface). The most common viewing angle used is 8°. The 8° angle approximates the 0° angle very closely since the specular reflection for 8° and 0° is almost the same according to the Fresnel equation.

The measurement data will include any specular reflection that is reflected into the viewing optics at the viewing angle. For a glossy sample the light from the area of the sphere at the mirror angle to the viewing optics (-8 degrees for d/8), will enter the optics. For a matte sample, the diffused surface light, which can be from any area of the sphere, will enter the optics.

Figure 7 and 8 show what happens when a glossy and matte surface is measured with this geometry. These two objects are identical in color and differ only in surface gloss. In Figure 7, the 4 arrows on the left of the sphere depict the incident light. In reality, light is coming from all areas of the sphere wall. Since this is a glossy object, Figure 7 also shows the light reflected from the sample by the 4 arrows on the right of the sphere. Again this is a simplification to help explain what is happening. In reality, the light is being reflected back at many angles. The glossy object reflects the specular directly into the viewing optics. This is shown by the bold arrow in Figure 7.

In Figure 8, we are again only showing 4 incident light beams. Since this is a matte object, the incident beams are diffused and are not reflected in the mirror direction as in Figure 7. The specular reflectance does not enter the optics directly but because of the matte surface, the diffused specular reflectance indirectly enters the viewing optics. Since the specular is included in each of the measurements, the measurement of the glossy object will be the same as the measurement of the matte object.
Specular Component Excluded (SCE) - d/0

This geometry adds the use of a specular port or gloss trap to the sphere. The specular port is an opening in the sphere wall placed at the mirror angle to the viewing optics. For a d/8 design, the specular port would be placed at -8 degrees from the normal relative to the viewing angle. When this port is open, no light from that area is available to reflect off the sample at the mirror angle and enter the optics.

Figure 9 shows an example with a glossy sample. There isn't any light available at the mirror angle (because of the open port) to enter the optics. Notice that the bold arrow is not there. The measurement includes only the diffuse reflection from the interior of the sample. No specular reflection enters the viewing optics.

Figure 10 shows an example with a matte sample. In this case the diffused surface light, which can be from any area of the sphere, will enter the optics. Notice that even though the bold arrow is not there, the diffuse reflection from the other arrows (incident light) will enter the optics. The measurement includes both the diffuse surface reflected light and the diffuse reflection from the interior of the sample. Some specular reflection enters the optics.

The glossy sample and the matte sample will have different measurements using this geometry. A color difference assessment will indicate that the glossy sample is darker and more saturated than the matte sample. The use of this geometry will improve visual agreement, especially in reference to the direction of the color difference, but the magnitude or size of the color difference typically does not always agree with a visual assessment. SCE has not been found to be a preferable geometry over SCI, except for specialized needs, in any major industrial application.
0/45 and 45/0 Geometries

0/45 instruments illuminate the sample at the normal to the surface (i.e. 90 deg to surface), with the viewing optics at an angle of 45 degrees to the normal. Some 0/45 designs also offer multiple viewing optics (circumferential) that place the viewing optics at fixed positions around the sample. 45/0 instruments illuminate the sample at 45 degrees with the viewing optics near the normal. Some 45/0 designs place the light sources in a ring around the sample at 45 degrees with the viewing optics near normal. The CS3 45/0 is of this type.

The 0/45 and 45/0 geometries exclude the specular component of the sample reflectance completely for a smooth or glossy sample but pick up some of the diffuse specular reflection of a rough or matte sample.

![Figure 11 - 4510 Gloss Surface](image1)

![Figure 12 - 45/0 Matte Surface](image2)

Figure 11 shows a 4510 configuration for a glossy sample. The illuminating light is incident on the sample at 45 degrees and the specular reflection is reflected back at 45 degrees. The specular reflection does not enter the viewing optics. Figure 12 shows a 45/0 configuration for a matte sample. For a rough surface or matte sample, the diffuse specular reflection from the surface is reflected in all directions and some will enter the optics.

Because observers usually rotate samples to avoid the specular, the 45/0 and 0/45 geometries correspond more closely to the viewing conditions that are normally used to view and compare colors. It is generally accepted that these geometries provide better agreement with visual assessments for samples with substantial gloss differences. Instruments with a 45/0 or 0/45 geometry have been used in quality control applications but have found limited utility in computer formulation and correction applications.
Why isn’t 0/45 the Preferred Geometry?

Even though the 0145 and 4510 geometries may provide the best agreement with visual assessments in cases where there is a significant gloss difference, they are not the preferred geometries for general work; especially when using a color computer for formulation and correction. The main reason for this is that the 0/45 or 45/0 design will always pick up any gloss variations, however slight, in its measurements. These gloss differences will be included in the measurement data without any user intervention pertaining to the validity of the data.

This gloss sensitive characteristic of the 45/0 design can cause problems in building colorant data files for a color matching system. If the primary samples used to make the colorant data file have gloss differences due to pigment loading, resin types, or even fingerprints or other surface irregularities, the primary data will be linked to these arbitrary gloss levels. They will not represent the true characteristic of the primary colorants.

Another possible problem area is in making batch corrections. All gloss differences are included in the spectral measurement data and will be interpreted as color differences. If the batch gloss varies from batch to batch, a correction program will interpret these gloss differences as color differences between the standard and the batch, and will attempt to make adds to compensate. This could lead to incorrect or oscillating adds. The SCI geometry masks these differences so that only the actual color differences are acted on.

The 45/0 and the 0/45 geometries, although more representative of the way we view real objects, are generally not best suited for overall work in the computer color field. There are some specialized areas such as quality control where these geometries have been used successfully. Unless there are specific requirements, it is probably better to use a SCI geometry, especially for new users of color systems.
What Is the Datacolor Gloss Function?

The Datacolor Gloss Function combines the virtues of both the d/0 and 0/45 or 45/0 geometries. It allows us to take a reflectance curve obtained from a spectrophotometer of d/8 SCI geometry and adjust the curve based on the sample's gloss value to be roughly what it would read on the other geometry. This adjustment moves the reflectance curve from the dimension or space of the specular included instrument, which we call “measurement space”, to a new dimension which we call “visual space”. The "Visual space" curve will be a better representation of the color and will agree more closely to the way we actually see the sample.

The function is derived from data obtained from measurements of a series of black samples, consisting of different gloss levels from matte to high gloss. A d/8 SCI and 0145 instrument were used to gather the necessary data. The d/8 SCI instrument will measure basically the same reflectance values for all these samples while the 0/45 instrument will produce varied reflectances based on the gloss of the samples. A visual appraisal of the samples indicated much greater visual color differences between the lower gloss samples (0 to 30 gloss) than the higher gloss samples (30+ gloss). This indicated that the visual change that is observed when viewing the gloss series was not a linear relationship. In other words, equal changes in gloss value did not produce equal visual changes.

The differences between the SCI data and the 0/45 data at each gloss level, when plotted, showed a non-linear relationship that seemed very similar to the perceived visual difference. It followed that it should be possible to adjust a SCI curve based on this relationship and obtain a new curve that would be similar to a curve actually measured on a 0/45 instrument. Since 0/45 measurements have usually been in better agreement to visual perception, this new curve should also agree better to visual than the SCI curve.

This method was tried and found to agree much closer with visual appraisals than SCI. In fact, the results were close to the data obtained from the 0/45 instrument. The benefit of this approach is that we can apply the gloss compensation only when we need it. We retain all the benefits of the SCI sphere geometry but we have the ability to correct certain curves based on this "visual" function. The function requires input of either a gloss value obtained from a glossmeter or a gloss factor obtained from a CS5/CS3 instrument.

4 See Appendix D for a graphical explanation.
Color Difference Before Gloss Correction

<table>
<thead>
<tr>
<th>Specular Included Color Difference of Gloss versus Matte Black Samples</th>
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</thead>
<tbody>
<tr>
<td>CIELAB Difference</td>
</tr>
<tr>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Std: GLOSS BLACK</td>
</tr>
<tr>
<td>Ill/Obs</td>
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<tr>
<td>---------</td>
</tr>
<tr>
<td>MATTE BLACK</td>
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The color differences shown above are from specular included measurements of a high gloss black sample and a low gloss matte sample. The gloss value of the high gloss sample is 91.0 @ 60' and the gloss value of the matte sample is 9.9 @ 60'. Visually the high gloss sample looks much darker than the matte sample.

Color Difference After Gloss Correction

<table>
<thead>
<tr>
<th>Gloss Corrected Color Difference of Gloss versus Matte Black Samples</th>
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<tbody>
<tr>
<td>CIELAB Difference</td>
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<td>---------------------------------------------------------------</td>
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<tr>
<td>---------</td>
</tr>
<tr>
<td>MATTE BLACK</td>
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</tbody>
</table>

After the gloss correction is applied the color differences agree with the visual appraisal. The matte sample is 5.69 units lighter than the glossy sample. The hue difference remains essentially the same. If this sample pair were measured on a 0/45 instrument, we would get almost the same result.
CS5 and CS3 Gloss Determination

The Datacolor Gloss Factor

The CS5 and CS3 with automatic specular ports can be used to determine a gloss factor of a sample. This gloss factor is an indication of the gloss of the sample, and can be interpreted like a gloss value from a specular glossmeter. The gloss factor is a relative number, which is correlated to actual specular gloss values of a set of gloss standards. The gloss factor will not always agree with values obtained from a glossmeter. The agreement between a gloss factor and an actual glossmeter reading will be dependent on the physical characteristics (refractive index and type of surface) of the calibrating gloss standards and the material being measured.5

Each instrument is calibrated for gloss at Datacolor by reading a common set of gloss standards. The actual glossmeter values of these gloss standards are entered into the calibration program. The set of gloss standards is then measured with the instrument and the correlation of gloss values is established. Even though the gloss factor may not always agree exactly with a glossmeter gloss value, the factor is close enough for use in the gloss compensation option.

If a closer correlation to actual glossmeter values is desired, the instrument can be gloss calibrated on a gloss ladder made of the material that will be commonly measured. For example, a paint company could make up a black paint gloss series and calibrate on that. The returned gloss factors would then correlate much closer to the actual glossmeter values of paints.

The CS5 and CS3 gloss factors can be used successfully as the input to Datacolor gloss compensation programs. They can also be used to quantify the gloss of a product and to determine gloss agreement. It is important to note however, that if product specifications specify that gloss be measured according to ASTM D 523 or that a specific glossmeter geometry be used, you MUST use a glossmeter. The gloss factor is not a replacement for a glossmeter when a glossmeter value is specified. In the absence of specific gloss specifications, the factor can be a convenient way to determine gloss agreements and the factor itself can be defined into a specification between users of CS5's and CS3's.

5 See Appendix E for Graphical Explanation.
APPENDIX A

Refraction of Light

Consider a ray of light passing from medium A into medium B. If the speed of light is greater in A than in B, the ray is bent toward the normal NN to the surface of separation, as shown in Fig. 13. If it is less in A than B, the ray is bent away from the normal.

![Figure 13](image)

A constant $n$ of the two media is defined by the ratio:

$$n = \frac{\text{speed of light in A}}{\text{speed of light in B}} = \frac{\sin i}{\sin r}$$

where $i$ is called the angle of incidence, $r$ the angle of refraction, and $n$ the index of refraction of B relative to A. When A is a vacuum, $n$ is called the (absolute) index of refraction of medium B. Since the speeds of light in air and vacuum are practically equal, the refractive index of a substance relative to air is practically equal to that relative to a vacuum. ⁴
APPENDIX B

Fresnel's Equation for unpolarized light:

Equation #1

\[
S = \frac{1}{2} \left( \frac{\sin^2 (i-r)}{\sin^2 (i+r)} + \frac{\tan^2 (i-r)}{\tan^2 (i+r)} \right)
\]

where \( i \) = angle of incidence
and \( r \) = angle of refraction

\( S \) = Specular Reflection

Since \( \frac{\sin i}{\sin r} \) = refractive index (n) of a film:

Equation #2

\[
S = \frac{1}{2} \left[ \frac{\cos i - (n^2 - \sin^2 i)^{1/2}}{\cos i + (n^2 - \sin^2 i)^{1/2}} \right]^2 + \frac{n^2 \cos i - (n^2 - \sin^2 i)^{1/2}}{n^2 \cos i + (n^2 - \sin^2 i)^{1/2}} \]

where \( i \) = angle of incidence
\( n \) = refractive index of film

\( S \) = Specular Reflection

With equation #2, the specular reflectance of an optically smooth film can be calculated. All that is required is the angle of the incident light and the refractive index of the film.

Example: Incident Angle = 8 degrees
Refractive Index = 1.5

Specular Reflectance = 4.00062%
APPENDIX C

SPECULAR GLOSS MEASUREMENT

\[
G = \frac{R_{\text{sample}}}{R_{\text{std glass tile}}} \times 100
\]

where \( R_{\text{sample}} \) = \%R of Sample Measured
\( R_{\text{std glass tile}} \) = Specular reflectance of black glass
tile of known refractive index
\( G \) = Specular Gloss Value

According to ASTM D 523, highly polished, plane, black
glass with a refractive index of 1.567 should be assigned a specular
gloss value of 100 for each geometry. The gloss value for glass of
any other refractive index can be computed from the Fresnel
equation. For example, glass with a refractive index of 1.527
would have gloss values of 89.2, 93.6, and 99.4 for the 20, 60, and
85-degree geometries.$^5$

When calibrating a specular glossmeter, you will measure a
black glass tile and adjust the meter to a predetermined value. This
value is supplied with the black glass standard and is based on the
refractive index of the black glass. If the black glass had a
refractive index of 1.527, you would adjust the meter to read 93.'6
for the 60-degree geometry. If the black glass had a refractive
index of 1.567, you would adjust the meter to read 1 00 for the 60
degree geometry.
A series of black samples varying in gloss from matte to high gloss were measured with an SCI, SCE, and 0/45 geometry. The Y values are plotted in Figure 14. The SCI values, Curve A in Figure 14, form a horizontal line across the chart indicating that there isn't any change between the samples. The SCE values, Curve B in Figure 14, indicate a change but a rather linear change. The 0/45 values, Curve C in Figure 14, indicate a change but a very non-linear change.

When viewing these samples arranged in order of increasing gloss, you will notice a much greater color difference (mainly lightness/darkness) between adjacent samples at the low gloss end than at the high gloss end. The visual appraisal of these samples agrees more closely with Curve C, the 0/45 relationship, than with Curve B, the SCE relationship, or Curve A, the SCI relationship.

**Delta Y for SCI-0/45 and SCI-SCE**

Figure 19 shows the delta Y values versus gloss. The delta Y's are the differences between the specular included measurements of the black gloss ladder and the 0/45 and specular excluded measurements of the black gloss ladder. The delta Y function for SCI-0/45 is used to adjust an included curve to visual space. The gloss value is chosen from the x aids and a vertical line is drawn until it intersects the SCI-0/45 curve. From this point a horizontal line is drawn to the y-axis and the delta y is read. This is the amount to subtract from the SCI curve.
Figure 16 - Gloss Determination and Gloss Function

Figure 20 shows how a gloss factor is obtained from an instrument and how that gloss factor is applied to obtain a corrected curve. The instrument takes an SCI and SCE read of the sample to obtain a delta Y value. This delta Y value is then used to obtain the gloss factor. In the top graph in Figure 20, this is shown graphically.

The bottom graph of Figure 20 shows the delta Y (SCI-0/45) versus gloss graph inverted 180°. This is done to show how the returned gloss factor (or glossmeter value) is used to obtain the delta Y used to adjust the SCI curve. From the gloss factor or value, a line is connected to the SCI-0/45 curve. From this point a line is drawn to the y axis to obtain the amount of Y or actually %R to subtract from the included curve.
References


