# H51: Gloss, Perception and Measurement

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[Colour4Free]

## Perception of gloss

Gloss or glossiness is an aspect of appearance that we all recognise and the degree of glossiness is described by adjectives such as:

- High gloss finish
- Gloss finish
- Matt Finish

High gloss is usually seen as a desirable attribute for some objects as in the remark "polish until you can see your face in it". Figure 1 shows three vases and most people would agree that the surface of the vase on the right-hand-side of Figure 1 is the glossiest and the surface of the vase on the left-hand-side is the least glossy finish.

*Figure 1: Vases with three different levels of gloss*

A similar impression of gloss level is obtained from the ring shown in Figure 2 and in Figure 3.

*Figure 2: Ring with a matt surface finish*

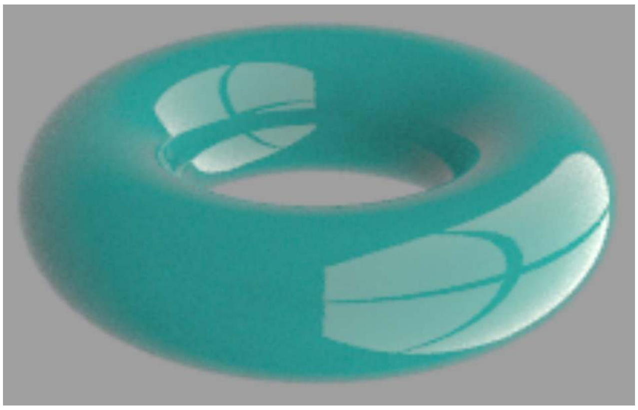

*Figure 3: Ring with a glossy surface finish*

### Appearance characteristics of gloss

The human visual system takes account of several types of appearance characteristics simultaneously and integrates them into a single estimate of glossiness. This is why different observers may reach different conclusions concerning the gloss level of the same object.

#### *Reflection of images*

Study of Figures 1 to 3 shows that the quality of the image of neighbouring objects reflected by the surface must have an important contribution to the impression of gloss. A definition of gloss is:

"the degree by which reflected highlights or reflected images of objects are seen as superimposed on the appearance of a surface"

#### *Major characteristics of gloss*

At the simple level the gloss can be regarded as the capacity of a surface to reflect light, and was defined in the 1930's by Hunter as:

"the degree to which a surface simulates the reflecting power of a perfect mirror"

Hunter defined the three major characteristics of gloss as:

*Distinctness-of-image gloss*

Distinctness of image gloss is a function of the sharpness of a reflected image; it is associated with high gloss surfaces in which mirror images are seen.

*Example*: The image of a window is clearly seen in the light reflection from the surface of the ring shown in Figure 4.

**Specular gloss**

Specular gloss is a measure of the brightness of the reflected image and is often associated with the bright patches of light on a surface that indicate the location of the illuminating light source. This type of gloss is clearly seen with high gloss surfaces and with medium gloss surfaces of paint, plastic etc.

*Example*: The surface of the black ball shown in Figure 5 has highlights where the light from the lamps above the ball is directly reflected towards the observer.

*Contrast gloss*

is a measure of the difference in brightness between the specular gloss areas (described previously) and other areas of the surfaces. It is associated with medium to low gloss surfaces of paint, plastic textile cloth etc.

*Example*: The upper surface of the vase in Figure 6 shows brighter areas where the light from the lamps is reflected more strongly towards the observer.

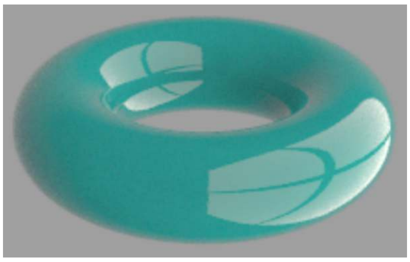

*Figure 4: Example of distinctness of image gloss*

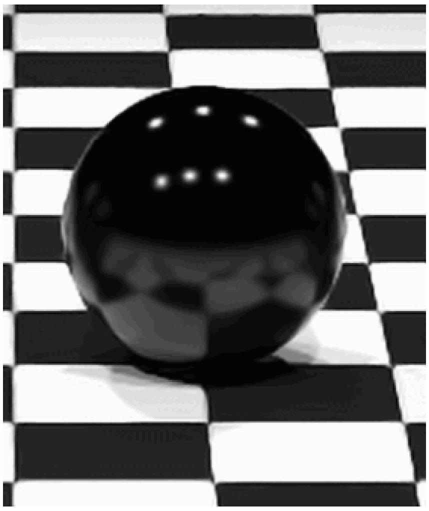

*Figure 5: Example of specular-gloss*

*Figure 6 Example of contrast-gloss*

## Surface reflection

At the surface of an object, the incident light is partially reflected (back from the boundary) and partially refracted (into the body of the material). The process is illustrated in Figure 7.

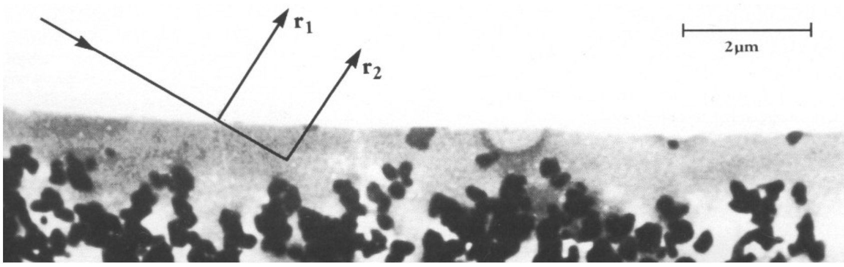


*Figure 7: Cross-section of a glossy paint layer showing reflection at the boundary and by pigments within the layer*

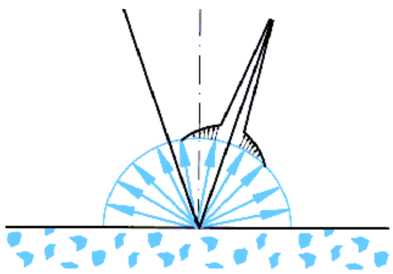

*Figure 8: Angular distribution of light reflected from the boundary and from within a pigmented layer*

Consider the interaction of light with a conventional type of glossy paint, the light reflected by the boundary will be distributed around the specular angle, whereas the light reflected by the pigments within the layer will be, to a good approximation, distributed evenly into all angles, Figure 8.

## Reflection of light at a boundary

The impression of the gloss of a surface is determined by the way the light shining onto the surface is reflected at the air-to-material boundary. For example, at a boundary between air and a sheet of glass, some of the light is reflected back from the glass surface and some is transmitted through the sheet.

The result of the action of an air-to-glass boundary in causing reflection and transmission of light is illustrated by the appearance of a shop window on a street in New York, as shown in Figure 9.

***Glancing angles of view***: The reflection of the street is clearly visible in the glass sheet. The objects within the shop cannot be seen through the window.


*Figure 9: Shop window on a Street in New York*

***Mid angles of view***:
The reflection of the light from the street is much reduced. The objects within this part of the shop are clearly seen through the window.

### Colour of the gloss-light

The gloss-light, the light reflected at the boundary, has the same colour properties as the light shining onto the source, as it has not entered the material at all. For example, in the street scene, the reflected image retains the colours of the original scene

In the case of the glossy ring, Figure 3, the gloss-light has the same “white” light characteristics as the light shining onto the object. In the gloss region, the white gloss-light has the effect of “diluting” the intensity of the coloured light that is being reflected from within the boundary of the material. In the high-gloss regions the additional white light dominates and the underlying colour of the object is no longer apparent.

### At the boundary

At a boundary between two materials that do not have the same refractive index, the incident light is partially reflected and partially refracted into the body of the material as illustrated in Figure 10.

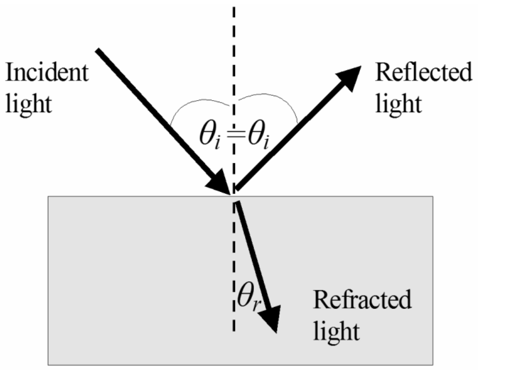


*Figure 10 Surface reflection and refraction*

***Dependence on refractive index***

The refractive index determines how a beam of light is reflected and refracted as it travels through a material. It is the ratio of the speed of the light in vacuum to the speed in the material.

$$n = \frac{speed\ of\ light\ in\ vacuum}{speed\ of\ light\ in\ the\ material}$$

Reflection and refraction of the light at the boundary will occur when there is a difference in refractive index between the material of the surface (glass has a refractive index of n = 1.5) and the surroundings (air has a refractive index of n = 1.0).

***Dependence on angle***

The amount of light reflected at a boundary changes with the angle the light makes with the boundary, for an air-to-glass boundary, as shown in Figure 11:

| | |
|---|---|
| Glancing angles: | All of the light is reflected, none is transmitted |
| Mid angles 45°; | About 10% of the light is reflected, 90% transmitted |
| Normal to surface: | About 4% of the light is reflected. 96% transmitted. |

***Background science***

The proportion of light that is reflected rather than transmitted is determined by the ratio of the refractive indices (*m*) of the two materials that form the boundary and the angle of incidence ( $\theta_i$ in Figure 10) the light beam makes with the boundary (Fresnel's law). For an unpolarised beam of light, the fractional amount reflected is

$$R = \frac{1}{2}\left[\frac{\sin^2(\theta_i - \theta_r)}{\sin^2(\theta_i + \theta_r)} + \frac{\tan^2(\theta_i - \theta_r)}{\tan^2(\theta_i + \theta_r)}\right]$$

The minimum amount of reflection is for light shining onto the surface at right angles or normal to the surface.

$$R = \left(\frac{m-1}{m+1}\right)^2 \quad \text{and} \quad m = \sin(\theta_i)/\sin(\theta_r)$$

Where

$$m = \frac{\text{refractive index of the object}}{\text{refractive index of the surrounding material}}$$

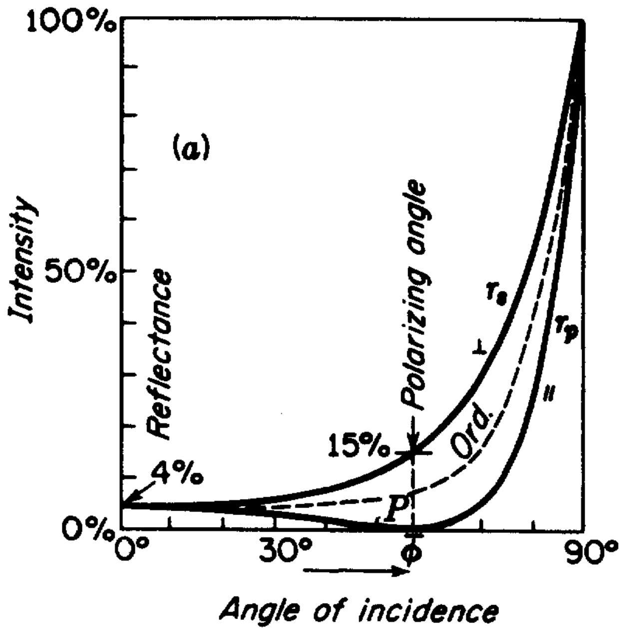


*Figure 11: Reflected intensity of light at an air to glass boundary at different angles of incidence*

The fraction of light transmitted through the boundary (*T*) is given by $T = 1 - R$

## Gloss and Surface roughness

The roughness of a surface and the refractive index of the materials determine the directions and the amounts of light reflected at the boundary between two materials. When the surface is not perfectly smooth, then the boundary reflected light is directed in to a range of angles around the angle of specular reflection and the impression of gloss is changed. This is illustrated in Figure 10.

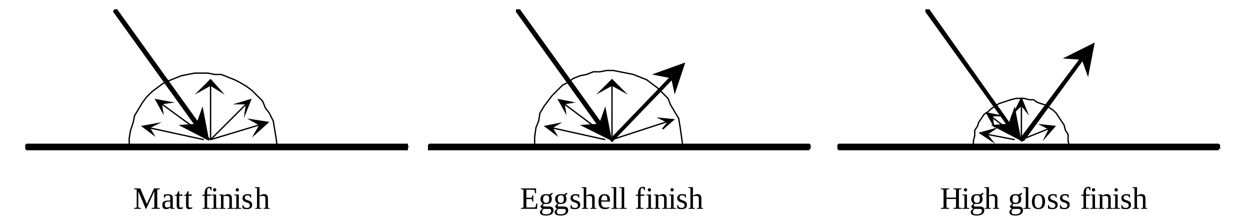


*Figure 10: Angular dependence of the boundary reflected light for surfaces with different levels of gloss*

### High gloss surface

Imagine that a beam of light is shone at a particular angle onto a very smooth surface. The boundary reflected light would all be along a narrow set of directions. An observer viewing such a surface will see, at certain viewing angles, reflected images of the surroundings. This gives rise to the visual impression of high gloss.

### Matt surface
The boundary of a very rough surface will tend to reflect light at many different angles, because the light meets the surface at many different angles. The boundary reflected light is diffuse in direction so that the observer cannot make out images of the surroundings. Consequently, the visual impression is that of a low gloss (matt) surface.

### Degree of roughness
The wavelength of light (380nm to 730nm) determines the length scale for measuring the roughness of a surface in relation to its influence on the gloss of a material. In general the following terms are often used:

Macro roughness: Variation in the surface height is greater than 1.0μm
Micro roughness: Variation in the surface height is less than 0.60μm

The influence of the roughness of a surface on the boundary reflecting properties was first studied by Lord Rayleigh (1901). Rayleigh wished to determine the maximum height (h) of step shaped defects (Figure 11) that could be present and still maintain an acceptable performance as a plane reflector (mirror). Rayleigh suggested that the maximum height of a step for light incident from an angle $\theta$ (Figure 12) is:

*Equation 1*: $$h = \frac{\lambda}{8 \cos \theta}$$

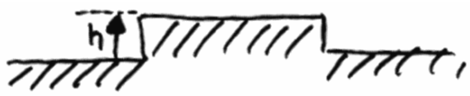

*Figure 11: Step height of surface defect*


*Figure 12: Angle $\theta$*

The maximum step heights at the three common angles of light incidence that are used for instruments that measure specular gloss are shown in Table 1.

The values in Table 1 show that the level of gloss at an assessment angle of 20° is over ten times more sensitive to surface defects than gloss assessment at an 85° angle of incidence.

*Table 1: Maximum step height ($\lambda$ = 550nm)*

| Angle of incidence / (deg) | Step height /(μm) |
|---|---|
| 20 | 0.073 |
| 60 | 0.138 |
| 85 | 0.789 |

## Measurement of gloss
The relationship between the angle of viewing, the surface roughness and the quality of the reflected image is illustrated by the values shown in Table 1, which suggests that:

- High gloss surfaces are best compared using an instrument with a measurement angle of 20°.
- Medium gloss surfaces are best compared using an instrument with a measurement angle of 60°.
- Low gloss surfaces are best compared using an instrument with a measurement angle of 85°.

### Scaling of Gloss units
Gloss is an appearance attribute that depends on our perception and interpretation of the quality of an image reflected from a surface. The quality of the gloss of an object is a mental comparison of the fidelity of the reflected image from the surface to an “imagined” image from a mirror-like surface.

The comparison material that is used to define 100 gloss units is optically smooth, black glass.

### Standard instruments for “Specular Gloss”
Two of the standards for the measurement of specular gloss are ISO 2813 and ASTM D523
The optical design of a specular gloss meter is shown in Figure 13.

A collimated beam of light from a tungsten filament lamp (CIE Illuminant A) is shone onto the surface at a defined angle. Light is collected from the surface and, by using optical baffles and lenses, only the specular reflected light is passed to the detector. An optical filter corresponding to the CIE Luminosity Function is placed in front of the detector so that the response simulates the "brightness" sensitivity of the visual system

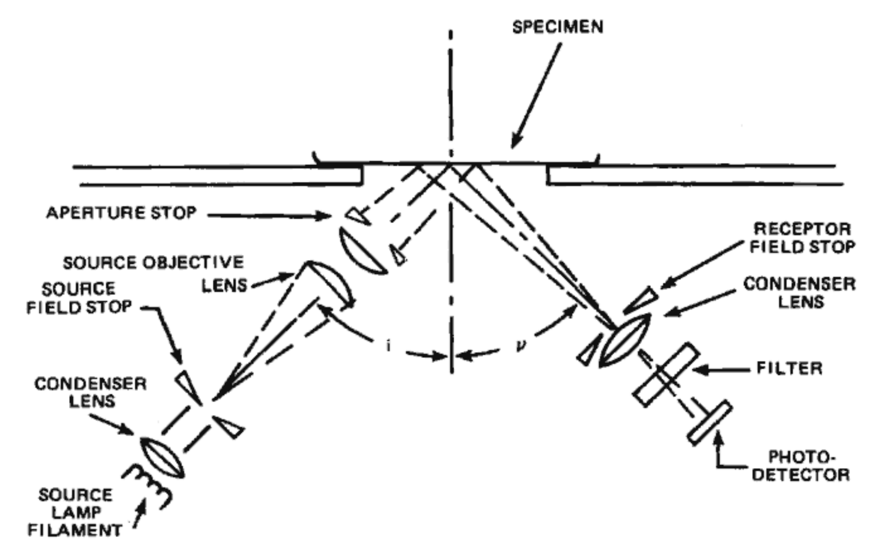


*Figure 13: Optical design of a specular gloss meter*

The gloss standard (black glass) is measured and the signal $R_s(std)$ obtained.

The surface under test is measured and the signal $R_s(pnl)$ obtained.

The gloss is determined from the relation shown in Equation 2:

*Equation 2*: $$\text{Specular gloss} = 100 \times \frac{R_s(pnl)}{R_s(std)}$$

The most common angles to use for the measurement are 20°, 60°, and 85°.

- The 60° angle instrument is suitable for most materials.
- The 20° angle instrument is recommended for high gloss materials, where the gloss is above 70 units at 60°.
- The 85° angle instrument is recommended for low gloss materials, where the gloss is below 10 units at 60°.

## Standard instruments for "Distinctness of Image" gloss

The distinctness-of-image gloss measurement is based on determining the spread of the light beam beyond the specular angle (ASTM5767-95).

ASTM D5767-95(2004) Standard Test Methods for Instrumental Measurement of Distinctness-of-Image Gloss of Coating Surfaces

In a DOI gloss measurement, the collimated beam of incident light is shone onto the surface at a particular angle, often 30 degrees.

The specular reflected light ($R_s$) is collected in a narrow band of angles that are equal but opposite to the incident angle (Figure 14).

The off-specular reflected light ($R_{0.3}$) is also collected at angles slightly away from the incident angle to determine the degree of angular spread of the reflected light. The off-specular reflectance is determined from the amount of light reflected at, and beyond, the angles (specular + 0.3°) and (specular – 0.3°).

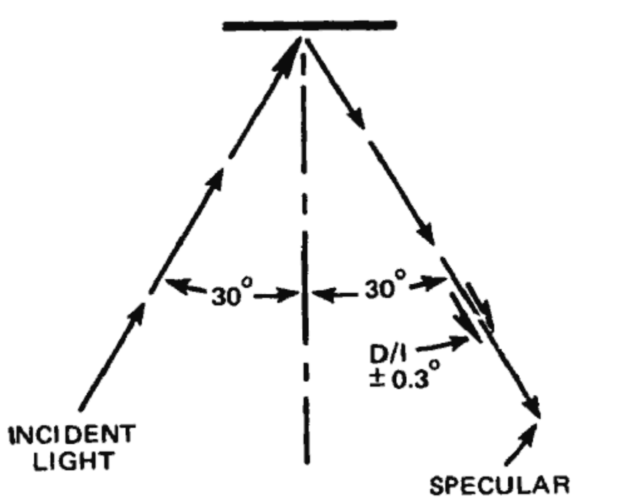


*Figure 14: Optical principle of a distinctness-of-image gloss meter*

The distinctness of image gloss value is determined from:

*Equation 3*: $DOI = 100 \times \frac{R - R_{0.3}}{R}$. where $R = \frac{R_s(pnl)}{R_s(std)}$

Where $R_s(std)$ is the $R_s$ value for black glass
$R_s(pnl)$ is the $R_s$ value for the panel

**Contrast gloss**

Contrast gloss is used to assess materials with a lower degree of gloss than both DOI gloss and specular gloss. There are not any established standards for the measurement of contrast gloss, Most methods of assessment use the principle of comparing the amount of diffuse reflectance ($R_D$.) from a panel with the total reflectance ($R_T$), the sum of diffuse and specular reflectance.

*Equation 4*: $Contrast\ gloss = 100\left(1 - \frac{R_D}{R_T}\right)$

A reflectance spectrophotometer with an integrating sphere type of optical system can provide estimates of two types of reflectance value. When the instrument measures in the specular light included mode (SPIN) then the Y tristimulus value can be used as an estimate of the visually weighted total reflectance $R_T$. When the instrument measures in the specular light excluded mode (SPEX), the Y tristimulus value can be used as an estimate of the visually weighted diffuse reflectance $R_D$.

*Equation 5*: $Contrast\ gloss = 100\left(1 - \frac{Y_{SPEX}}{Y_{SPIN}}\right)$

This measure of contrast gloss is zero for a matt panel and increases as the level of contrast gloss increases.

## Bibliography

Figure 13 and Figure 14 have been adapted from figures in:

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

ASTM D5767-95(2004) Standard Test Methods for Instrumental Measurement of Distinctness-of-Image Gloss of Coating Surfaces

ASTM D523-89(1999) Standard Test Method for Specular Gloss

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