

dti

**A NATIONAL MEASUREMENT
GOOD PRACTICE GUIDE**

No. 94

Good Practice Guide for
the Measurement of Gloss



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Measurement Good Practice Guide No.94

Good Practice Guide for the Measurement of Gloss

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Quality of Life Division

ABSTRACT

This guide describes how gloss is specified and measured. It contains recommendations on how to obtain the suitable results for a given application, including descriptions of technology and the assessment of uncertainties.

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Approved on behalf of the Managing Director, NPL
by Nigel Fox, Quality of Life Division

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Introduction

1

IN THIS CHAPTER

- What is gloss?
- Best practice in gloss measurement

1.1 What is Gloss?

Gloss is an important aspect of our visual perception of objects, second arguably only to colour. Everyone *thinks* they know what gloss is - it is a mirror-like front surface reflection. That said, a mirror is seldom regarded as being highly glossy, suggesting that both qualitatively, and quantitatively, describing gloss is more complicated. A better description might be that gloss relates to the reflection of *highlights*. The perception of gloss also relates to finish (the magnitude, frequency, randomness and scale of curvatures), texture (changes in reflecting properties over the surface) and how a sample is illuminated and viewed.

It is possible for three people to use inconsistent or even contradictory criteria to describe gloss, leading to different ranking of a set of samples.

Psychophysical measurements can be used to derive a perceived gloss scale, but the range of different judgement criteria can give a considerable spread of individuals' scales. This is similar to models used to specify colour based on the average experience of about 50 observers in that although these models may predict that two spectrally different colours appear as the same colour, every human being might actually see a mismatch.

Gloss may be measured by several different optical and analytical techniques, yielding a variety of answers. This guide helps anyone requiring a gloss assessment to decide which method is appropriate for a given application.

It is important to understand the *quality* of results (in terms of both clarity in provenance and calibre of result). 'Measurement accuracy' is a much valued but poorly understood quantity. This guide explains the more tangible concepts of measurement uncertainty and error. How to evaluate measurement uncertainty, investigate experimental error, and incorporate traceable measurements as part of a quality system is described.

The NPL 'Good Practice Guides' listed in Section 15 are written to meet the needs of different levels of expertise. This guide aims to help the reader measure gloss appropriately, and interpret and use results in a way acceptable to quality systems. References are given for those needing further information or a deeper understanding of aspects described.

While in many cases, the methods presently used will continue to serve us well; there is a big difference between existing gloss scaling methods, and what humans perceive as gloss. The future of gloss measurement and specification lies in a better understanding of what it is, which is the subject of a still-evolving science. This document describes where we are at the start of the 21st century. The author suspects that even a few years later, research into *soft metrology* (related to measurements of the responses of our senses), and developments in computer graphics could promote us from the present situation with a scale based on a piece of glass with a particular refractive index to a more complicated visual gloss model founded on a greater understanding of the intricacies of the human visual system.

1.2 Best Practice in Gloss Measurement

This guide comprehensively describes many elements of best practice. Industry seldom has resources or ability to address all of these elements fully and so this guide aims to provide some guidance on priorities for particular applications.

The following is a ‘top five’ list of factors to consider. The exact order and relevance of these and other factors will depend on the application.

<u>Issue</u>	<u>Section</u>
1 Traceability.	6.4
2 Sample and instrumental cleanliness.	7.2
3 Provenance: records of geometry, instrument, operator, traceability (date of most recent calibration), sample measurement conditions, sample cleanliness state, sample orientation.	
4 Geometry/measurement method.	4
5 Understanding the uncertainty in the result.	6.2

A full list of all considerations is given in Table 6.3, and descriptions of the components in Section 6.6.

Describing Gloss

2

IN THIS CHAPTER

- How light interacts with surfaces
- Empirically modelling gloss
- Six ways to describe gloss
- Material optical properties affecting perceived gloss
- Relating specular reflectance to refractive index
- Specular gloss units and how they relate to specular reflectance
- The metallic perfect mirror gloss scale
- Bi-directional reflectance distribution factor (BRDF)
- Specular included and specular excluded geometries
- Visual assessment of gloss

2.1 How Light Interacts with Surfaces

Light illuminating an object can be:

- absorbed within it (a process largely responsible for colour)
- transmitted through it (relating to the properties of transparency, opacity and clarity)
- scattered within it (related to diffuse reflectance and transmittance, translucency and some definitions of haze)
- reradiated with lower energy (e.g. fluorescence)
- specularly (also called regularly) reflected.

The final interaction listed above is the main factor responsible for the property *gloss*. Strictly speaking, specular reflection is at the angle opposite that of illumination (with angles referred to the surface normal). Surfaces do not reflect solely in a planar fashion – often scattering causes a *spread function* in reflectance about the specular angle, blurring a reflected image. Other interactions can affect gloss to a lesser degree.

Gloss, a psychophysical phenomenon, may be defined as:

‘The attribute of surfaces that causes them to have shiny or lustrous, metallic appearance.’
[1]

or

“The mode of appearance by which reflected highlights of objects are perceived as superimposed on the surface due to the directionally selective properties of that surface.”
[2]

The latter definition more explicitly suggests the dual nature of gloss – relating to both perception of images and highlights. Many criteria are used to judge and measure gloss, chiefly because these two different aspects are perceived differently.

Metallic materials reflect and scatter most incident light from the first few atomic layers of the surface, with little light penetration beyond. This makes them suitable for mirrors. Oxidation reduces reflection and increases scattering, so a transmitting coating is usually applied to prevent this. Dielectrics (non-metals) mainly reflect light from deeper within the substance. For example, typically, a glossy ceramic can specularly reflect 4% of incident light at the gloss angle.

2.2 Empirically Modelling Gloss

Gloss relates to flatness. It is recommended that primary reference standards should be flat to within 2 fringes ($0.5\ \mu\text{m}$) per centimetre measured by optical interference, and most good standards are within this criterion. A surface may be considered to comprise of microscopic elementary facets set at various angles to the mean surface plane [3]. These facets can be of two types: the first, randomly orientated, diffusing a proportion of incident light in all directions thus giving a matt appearance, and the second, parallel to the macroscopic tangent, causing a mirror-like reflection at the specular angle.

Lambert's cosine law describes the matt component of reflection. This states that for a perfectly rough or diffuse surface, incident radiation is retransmitted in an angle θ to the sample surface normal with an intensity proportional to $\cos(\theta)$. The Helmholtz reciprocity theorem [4] suggests that the directions of light in ray tracing diagrams may be reversed. By combining the two laws, it may be shown that the intensity of light reflected at a fixed angle will vary by $\cos(\theta)$, where θ is the angle between the source and the sample normal.

A term describing the reflectance of the glossy component of light is added to Lambert's law in Phong's law [5]. The two laws are empirical. The latter was developed for the computer graphics industry in the mid 1970s and is summarised in Equation 2.1:

$$\text{Reflectance}(\theta, \Phi) = k [r_d \cos(\Phi) + (1 - r_d) \cos^m(\Phi - \theta)] \quad \text{----- Equation 2.1}$$

where θ is the incidence or specular angle and Φ is the observation angle. The percentage of incident power that is reflected diffusely is defined by r_d . The mode number 'm' gauges 'shininess', describing the spread of the glossy component with angle as shown in Figure 2.1.

Figure 2.1: Examples of functions from Phong's law showing specular spreads from several mode (m) values.

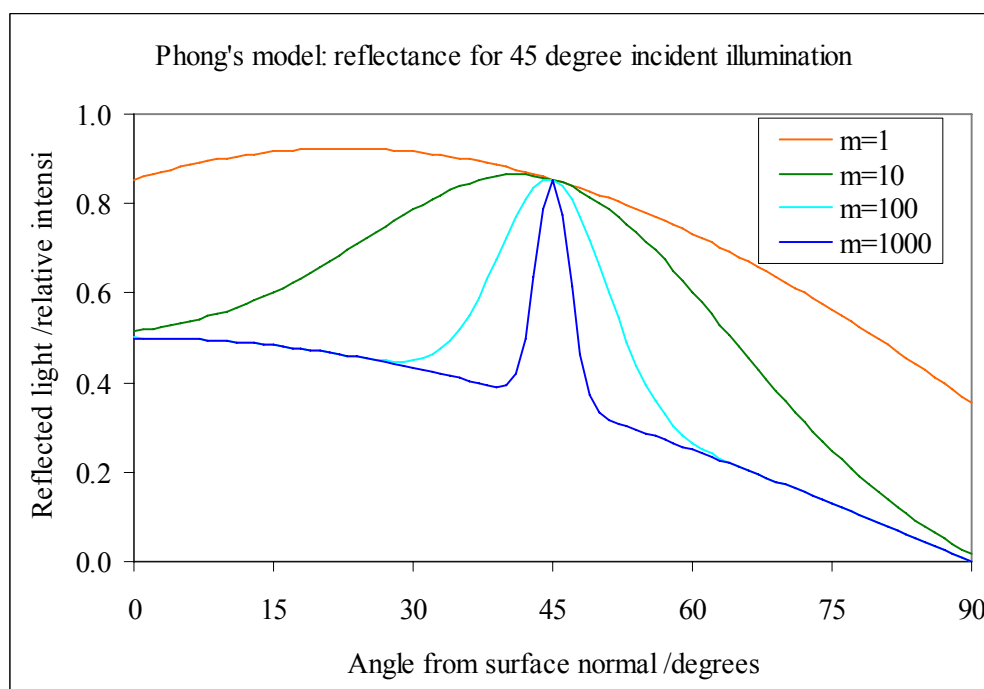
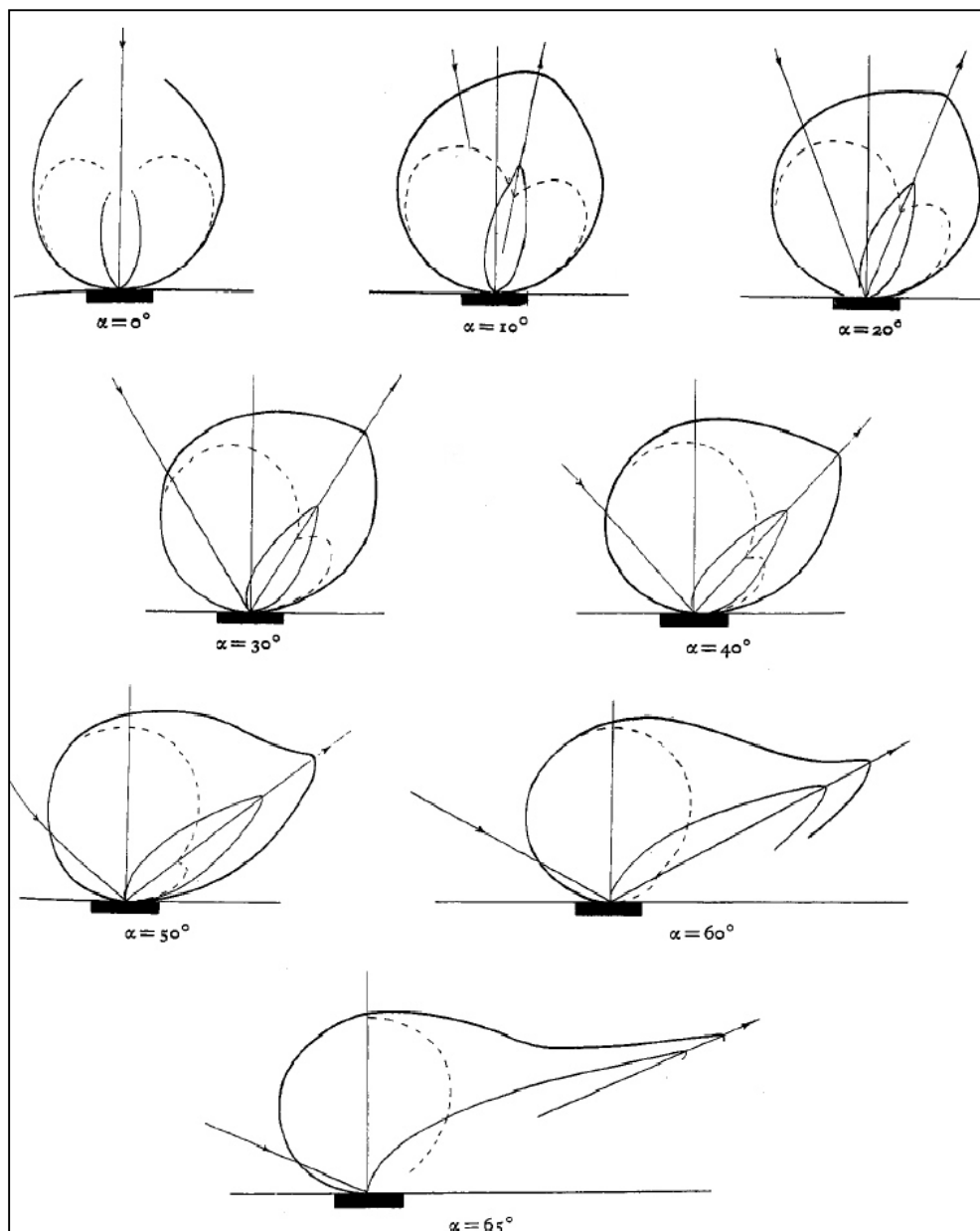


Figure 2.1 shows how light can be reflected from a flat surface, as a function of angle of detection away from the surface normal and opposite the incident beam (in this case incident at 45°). As m is increased, the spread of the specular peak of light sharpens. In the figure, $r_d = 0.5$.

In his 1939 paper [6], W. W. Barkas shows how Lambert's law can be derived from a mathematical model of a surface comprising microscopic facets of random inclination. Furthermore, by varying the distribution of bias of facet orientation, with more parallel to the surface, the spread of light reflected about the specular angle can be modelled. The result for one facet bias is given in figure 2.2 showing how light is reflected by Bristol board. What is modelled particularly well is the increase in glossy component with specular angle (relative to the surface normal). This apparent increase in glossiness at glancing angles is called *sheen*. (See next section.)

Figure 2.2: Modelled reflectance of light from Bristol board.



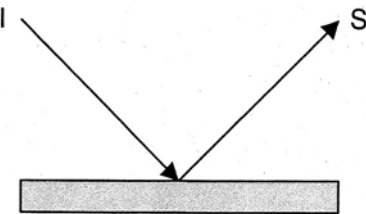
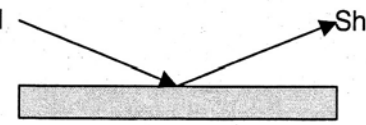
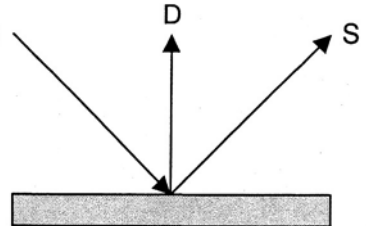
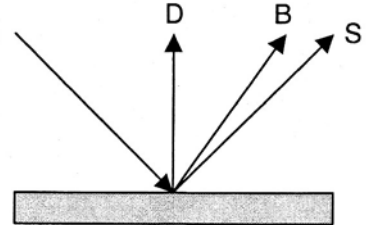
2.3 Six Ways to Describe Gloss

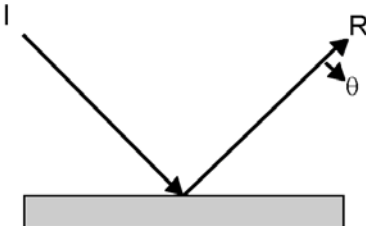
The amount of specularly reflected light may vary:

- at the specular angle, as a proportion of incident flux
- about the specular angle (modelled by the ‘shininess’ term in Phong’s law above)
- with angle of illumination.

In 1934, Hunter designed a glossmeter to measure light specularly reflected at 45° to the surface normal. After studying the characteristics of many materials he determined six different visual criteria for ranking (or measuring) their gloss [1] as shown in Figure 2.3.

Figure 2.3: Hunter’s six ways to describe gloss.

(1) Specular Gloss	The ratio of light reflected at a specified angle to that incident on the surface at the same angle on the other side of the surface normal.		$G \propto \frac{S}{I}$
(2) Sheen	Gloss at grazing angles of incidence and viewing.		$G \propto \frac{Sh}{I}$
(3) Contrast Gloss (also called Lustre and Haze)	Ratio of specularly reflected light and that diffusely reflected normal to the surface.		$G \propto \frac{S}{D}$
(4) Absence-of-Bloom	A measurement of the absence of haze or a milky appearance adjacent to the specularly reflected light.		$G \propto \frac{B-D}{I}$

(5) Distinctness-of-Image	Sharpness of specularly reflected light.		$G \propto \frac{dR}{d\theta}$
(6) Absence of Surface Texture Gloss	Perception of surface smoothness and uniformity.	Overall visual assessment.	

To illustrate the above in practice these may be interpreted as *perceived* -:

- (1) specular reflection brightness
- (2) shine at grazing angles for samples perceived otherwise matt
- (3) relative brightness of specularly and diffusely reflecting areas
- (4) cloudiness in reflection near the specular angle
- (5) sharpness of reflected images in terms of contrast
- (6) surface smoothness and uniformity.

2.4 Material Optical Properties Affecting Perceived Gloss

- *Surface film* (either an intentional over-coating, or build up of contaminant or dirt) can result in a thin (potentially non-uniform) surface with properties different to the bulk material. This can introduce a bluish cast, probably through Rayleigh light scattering.
- *Curvature of sample* (above the mm scale) enhances the visibility of glossiness but presents an issue for instruments designed to measure flat surfaces only.
- *Surface finish unevenness* (near the mm scale) causes a surface appearance termed *orange peel*. Orange peel finish is a particular problem to the automotive industry where it appears when acrylic undercoats are coated with lacquers. It is also evident in the glazes of ceramics.
- *Polarisation of light*. Light specularly reflected by metallic surfaces is partially elliptically polarised, while non-metallics introduce some linear polarisation. These factors, though small, peak at about 60° and can cause variations in results from instruments with different polarisation responsivities [7].
- *Orientation of sample*. Some materials – such as velvet – have gloss properties that vary considerably with rotation.

2.5 Relating Specular Reflectance to Refractive Index

Equations 2.2 and 2.3 are mathematical models derived from Fresnel's equations [8] which describe relationships between specular reflectance, measurement angle and sample surface refractive index. They can be used to calculate the theoretical reflectances R_s and R_p for incident light polarised in s (senkrecht=perpendicular) and p (parallel) planes respectively, for a sample of refractive index n .

$$R_s = \left(\frac{\cos \theta - (n^2 - \sin^2 \theta)^{1/2}}{\cos \theta + (n^2 - \sin^2 \theta)^{1/2}} \right)^2 \quad \text{----- Equation 2.2}$$

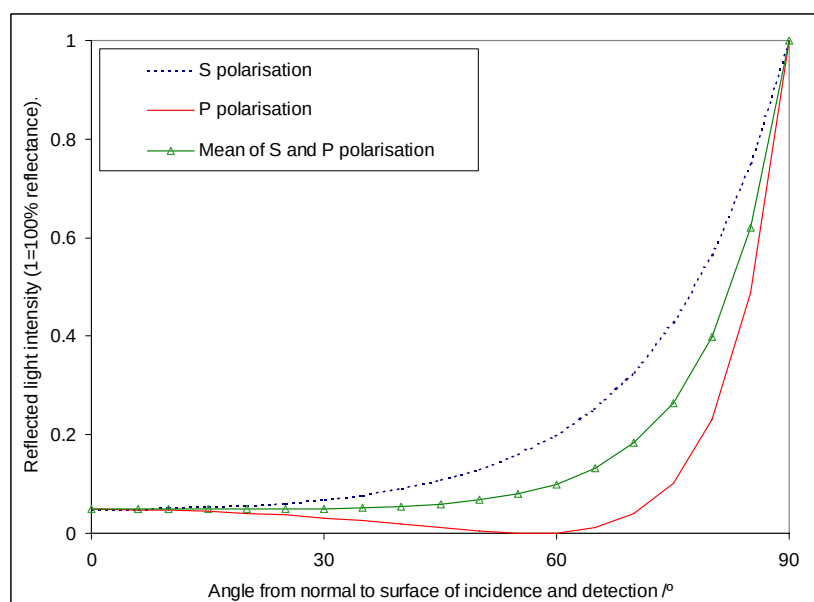
$$R_p = \left(\frac{n^2 \cos \theta - (n^2 - \sin^2 \theta)^{1/2}}{n^2 \cos \theta + (n^2 - \sin^2 \theta)^{1/2}} \right)^2 \quad \text{----- Equation 2.3}$$

The mean of R_p and R_s give a value for reflection R from unpolarised illumination in Equation 2.4.

$$R = (R_s + R_p)/2 \quad \text{----- Equation 2.4}$$

Equations 2.2-2.4 were used in a spreadsheet to generate Figure 2.4.

Figure 2.4: Functions for specular reflectance for surface of refractive index 1.567



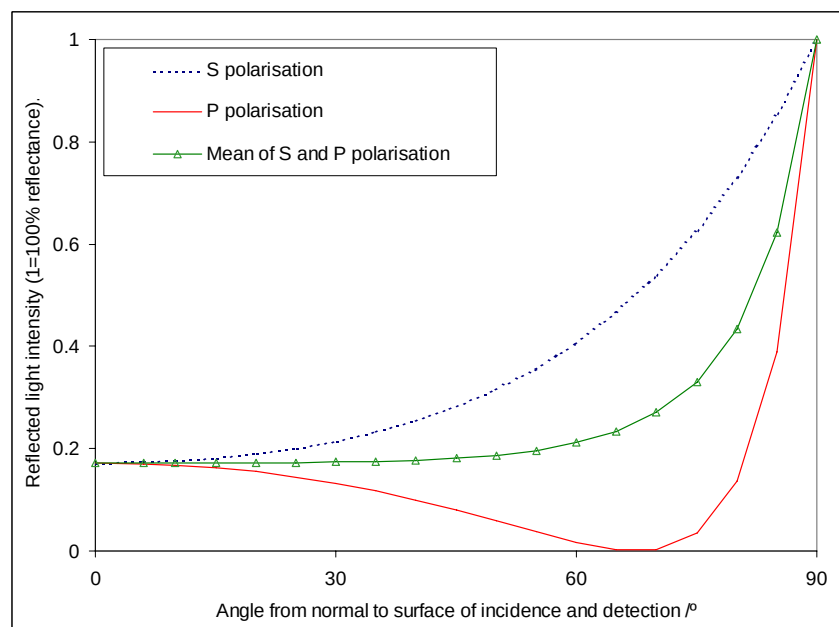
At one angle, the p polarisation component is zero. Evaluating this angle from refractive index was first described by Brewster in the early 1800s and it is named after him. The simple relationship is given in Equation 2.5.

$$\text{Brewster Angle} = \arctan(n_2 / n_1) \quad \text{----- Equation 2.5}$$

Where n_1 and n_2 are the refractive indices of the two media the light is passing between.

Putting the refractive index of diamond into the spreadsheet gives profiles illustrated in Figure 2.5.

Figure 2.5: Specular reflectance for surface of refractive index 2.419 (diamond)



Algebraic manipulation of previously given equations can enable the determination of refractive index from reflectance values. Surface roughness and film coating will affect gloss, so evaluated refractive indices using this method, or by the determination of the Brewster Angle, will tend to generate results different from book values.

2.6 Specular Gloss Units, and How They Relate to Specular Reflectance

ASTM D523, the most popular standard gloss measurement description [9], contains the core definition of specular gloss units (SGU) which states:

*a glass of refractive index $n = 1.567$ at 589.3 nm
has a specular gloss value of 100 SGU
for any angle of incidence.*

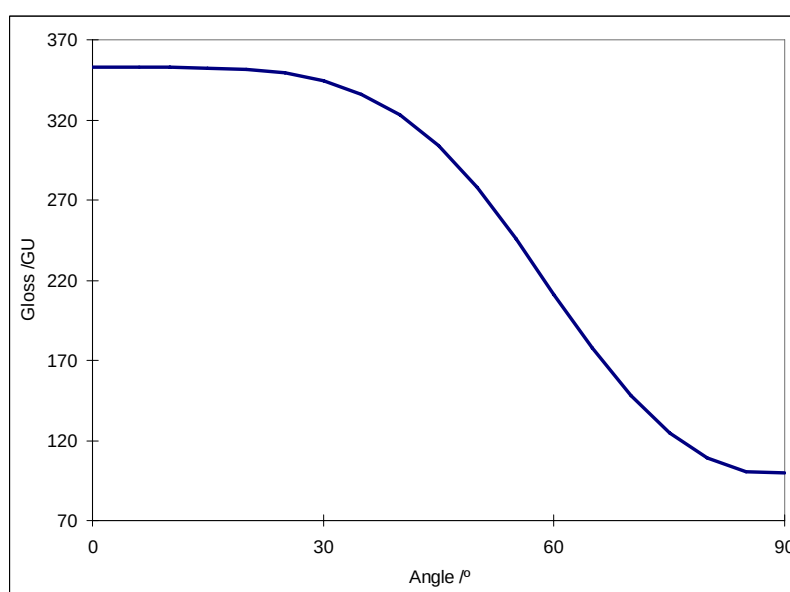
Substituting $n=1.567$ into the previous equations, or by reading Figure 2.4, we obtain:

Angle /°	Reflectance giving 100 SGU /%	Factor
20	4.908	20.376
60	10.006	9.994
85	61.915	1.6151

The values in the 'Factor' column multiply measured reflectance to provide a result in gloss units (=100/reflectance).

By multiplying the ratio of the results for unpolarised light of Figures 2.5 and 2.4 by 100 SGU, the function of theoretical gloss of diamond with angle can be found. The results are illustrated in Figure 2.6.

Figure 2.6: Calculated values for SGU of polished diamond



Details in the defining and realisation of the SGU scale (summarised below) may lead to small (<0.5%) uncertainties in results:

- The definition is based on a polished surface with refractive index of 1.567. This could mean anything between 1.56650 and 1.56749. One value in this range gives a value of reflectance at 60° of exactly 10% (which was an original intention).
- The system is based on a definition of refractive index at 589.3 nm (sodium D line), yet calls for measurements made with a broadband CIE Illuminant C (a daylight simulator) with a photopic detector (a human eye response). For typical glass, refractive index varies slightly with wavelength (by the property called dispersion). A weighted re-evaluation of effective refractive index for illuminant C with photopic detector gives a result about 0.0018 higher than for the 589.3 nm single wavelength case. This decreases the above factors to those given below:

Angle /°	Factor for Illuminant C, photopic response including effect of typical dispersion in glass
20	20.276
60	9.966
85	1.6147

- In 1980 [9] a luminous reflectance based primary standard recommendation was first published, but 25 years later, at the time of writing, the gloss unit definition remains unchanged. The reason for this is that evaluating refractive index accurately is simpler and more commonplace than gonireflectometry [11].

2.7 The Metallic Perfect Mirror Gloss Scale

Some measurement standards scale the gloss of metallics in a different way to the SGU method, by ascribing a value of 100 (at all angles) to a ‘perfect mirror’. This leads to a scale differing by a factor of ten from the SGU system which measures about 1000 SGU for a perfect mirror.

2.8 Bi-Directional Reflectance Distribution Factor (BRDF)

BRDF measures target reflectance as a function of wavelength, illumination geometry and viewing geometry. It is determined by structural and optical properties of the surface, including shadow-casting, multiple scattering, mutual shadowing, transmission, reflection, absorption and emission by surface elements, facet orientation distribution and facet density.

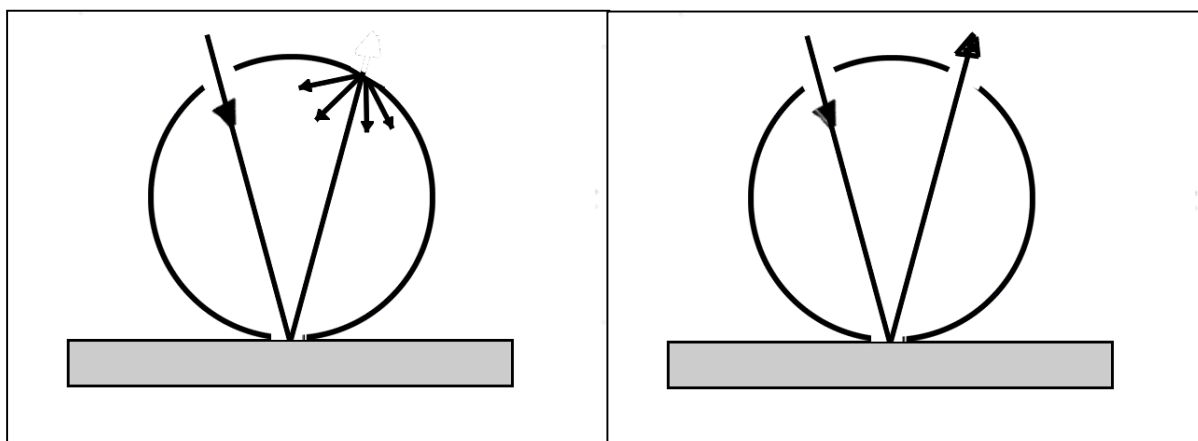
In principle, the various gloss metrics could be derived from a subset or summation of BRDF values.

Whilst measurement of BRDF might be argued to relate to gloss measurement, it is generally considered as a topic in its own right and the reader is directed elsewhere [12] for more details.

2.9 Specular Included and Specular Excluded Geometries

Measuring integrated hemispherical reflectance using traditional CIE recommended [13] geometries employs integrating spheres. The methodology permits the inclusion or exclusion of the component of specularly reflected light by including or excluding part of the sphere as shown in Figure 2.7.

Figure 2.7: Specular included (left) and excluded (right) geometries.



To a first approximation, the difference between results from these two measurement geometries gives an indication of glossiness, for example the difference for glossy ceramic tiles may be typically 4-6%. The scale used here relates to a 100% value for a sample reflecting all light. There are a couple of problems in using this method:

- The value may vary with diameter of the omitted sphere wall area because the ‘gloss’ component has a spread function.
- Such instrumentation commonly uses a measurement angle of about 8° , which differs from angles traditionally used to measure gloss.

Consequently it is rarely proposed as a recommended method in any written standard.

2.10 Visual Assessment of Gloss

A good practice for visual evaluation of gloss is described by Hunter and Harold [14].

The recommended ‘patterned light source’ rig comprises a fluorescent lamp in a holder with a wire grid placed in front of the lamps, and black velvet backing behind them.

Low gloss samples should be viewed by examining reflected light from the tubes at high (near-grazing) angles, while high gloss samples should be examined at near perpendicular angles.

The pattern of light and dark caused by the lamp and wire grid can be used to examine 'gloss' by looking at the amount of light reflected at the specular angle, and 'haze' by the amount of light reflected near to the specular angle.

To minimise the effect of sample size, the use of masks to make different samples of comparable size is recommended.

Measurement Standards for Gloss Measurement

3

Measurement Standards for Gloss Measurement

A survey of written measurement standards carried out by NPL in 2000 [15] identified the word ‘gloss’ in about 150 titles of standards. This illustrates the wide range of industries using gloss measurement listed in Table 4.1. A shorter, updated list of standards is given in Section 11.

The ASTM (American Society for Testing and Materials) has been the major player in the development of gloss measurement written standards.

In 1925, ASTM Standard Method D523 (most recently updated in 1999) was based upon an instrument constructed by Pfund [16] that illuminated and detected at 20° to the surface normal. The standard actually permits measurement at one of three angles (see section 4). Many standards use specular gloss measurement, and are industry-relevant versions of ASTM D523 and its national equivalents.

However, with the advent of affordable moving head instrumentation, imaging detectors and microprocessors, more standards featuring other types of gloss method are appearing. This trend is clearly illustrated by the number of recent ASTM standards listed in Section 11.1. Whether these methods will be adopted by individual industries and promoted through further standards remains to be seen. It is possible that confusion over exactly which gloss descriptor is appropriate for any given application will cause reluctance to replace a system, however arbitrary, which has ‘worked to date’. This reluctance to evolve is exemplified by the case of a recently manufactured instrument capable of measuring most of Hunter’s gloss types illustrated in Figure 2.2. Despite its good performance, and relatively low cost, the device failed to sell in sufficient volume to make it a viable product line.

ASTM D523 and the many other standards which use its methods prescribe measurements with an incandescent lamp (source A) and a detector with a photopic ($V(\lambda)$) spectral response. Commercial instrumentation complies with this requirement to varying degrees: some newer models deviate by using LED sources with spectral power distributions different from that required.

Further research is needed on the ways in which these departures cause significantly erroneous results – the error will vary from one sample to another.

Which Gloss Measurement Method is Appropriate?

4

Which Gloss Measurement Method is Appropriate?

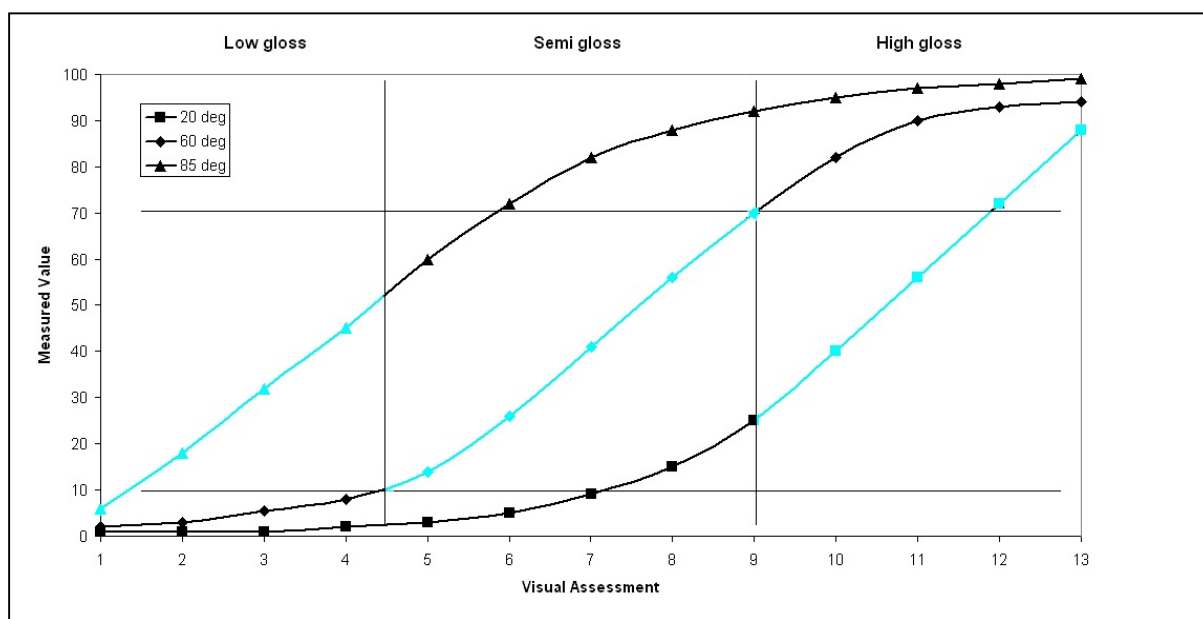
Care is needed in choosing an appropriate gloss measurement method. As mentioned in Section 2.3, the perception (and ranking) of the gloss of an object can be affected by other optical properties such as its lightness. A good example of this is that although two tiles might be measured to have the same specular gloss, a black tile looks shinier than a white one, so in this instance measuring contrast gloss might be more appropriate.

The reason why ASTM Standard Method D523 permits the use of either 20°, 60° or 85° is to accommodate a wider range of visible gloss. This is implicit in the recommended method:

To select the appropriate specular geometry to use: First measure the sample using 60° geometry. If the gloss value is higher than 70 SGU (high gloss) then re-measure at 20°, and if less than 10 SGU (low gloss) re-measure at 85°.

Figure 4.1 represents the results of some samples reported by Byk-Gardner [17], which measured gloss at all three angles permitted by the Standard Method.

Figure 4.1: Results of 13 samples in order of perceived glossiness, each measured using three geometries.



In Figure 4.1 the cyan line sections indicate how the three geometries cover the gloss scale in a reasonably linear fashion. High gloss samples are better discriminated by using the 20° geometry, while low gloss samples are most sensitively measured using the 85° geometry.

The curve shapes originate from the gloss equations given in section 2.5, though considerable rescaling accounts for the non-linear relationship between refractive index and perceived gloss value. At the time of writing of this guide, this “rescaling” is a contentious issue as the perception of the different forms of gloss means that the judgement of real samples seldom fits such an idealised picture. Work is presently being conducted to examine these aspects [18, 19].

Table 4.1 indicates the range of gloss measurements methods used in different industries, and may assist in deciding which method to use.

Table 4.1: Industries and the forms of gloss measurements for which they have standards.

type	specular						polarisation contrast	contrast	2-parameter	distinctness of image
angle /°	85	75	60	45	20	0	57.5	45 or 60	45 or 60	30
application										
paints	matt		mid gloss		high			low gloss		very high gloss
plastics			mid gloss	clear films	high gloss films & laminates					very high gloss
paper		coated papers, inks			cast coated papers, waxed paper, inks		low gloss white paper	ledger & writing papers		
ceramics			mid & low gloss	abraded tiles, porcelains.				porcelains		architectural ceramics and porcelain
textile								fibres, yarns, fabrics		
wax & floor finishing			all							
automotive					finishes					body coating & trim materials
appliance					finishes	enamels				enamels
metals						surfaces			high gloss	finishes
general materials	low-mid gloss	low-mid gloss	mid gloss	mid-high gloss	high gloss	high gloss	low gloss	low gloss	high gloss	mid-high gloss

Table 4.2 supplements Table 4.1, giving greater detail of the type of sample measured and the relevant standard. In many cases, the list of standards given is not exhaustive – many equivalents are given in Section 11.

Table 4.2: Gloss measurement methods with examples for illustration linked to appropriate written standards.

Gloss type	Applications	Paper Standard
sheen 85°	flat matt paints, camouflage coatings	ASTM D523,... etc
specular gloss 75°	papers – uncoated, coated, waxed, glassine	JIS P8142; JIS Z8741, TAPPI T480
specular gloss 60°	paints and plastics.	ASTM D523,... etc
specular gloss 45°	high-gloss paints; polyethylene and other plastic films; porcelain, plastics	ASTM C346,...
specular gloss 20°	high gloss plastic film, appliance and automotive finishes	ASTM D523,... etc
specular gloss 0°	metal surfaces	JIS Z8741
polarisation contrast gloss	white paper, low gloss	JIS Z8741 (obsolete)
contrast gloss at 45°, 60° and near normal	paper and paperboard	MERKBLATT V/22/72 (German)
2-parameter gloss (ϕ/ϕ') x 100 (at 45° or 60°)	smooth metal, or high-gloss non metals	JIS Z8741
30° distinctness of image gloss; 35° narrow angle haze	high gloss image reflecting non-diffuse metal surfaces	
contrast lustre $100(r_s/(r_d+r_s))$	textiles, low-gloss paper, other materials	
image gloss (visual observations of rings)	porcelain-enamel.	ASTM C540

Instrumentation

5

IN THIS CHAPTER

- Light sources and detectors for gloss measurement
 - » Sources
 - » Detectors
- Types of instrumentation
 - » Fixed few detector/illuminator
 - » Mobile single detector/illuminator (Goniometer)
 - » Multi detector array
- How results vary with time
 - » Over short time periods
 - » Over minutes
 - » Over longer time periods

5.1 Light Sources and Detectors for Gloss Measurement

5.1.1 Sources

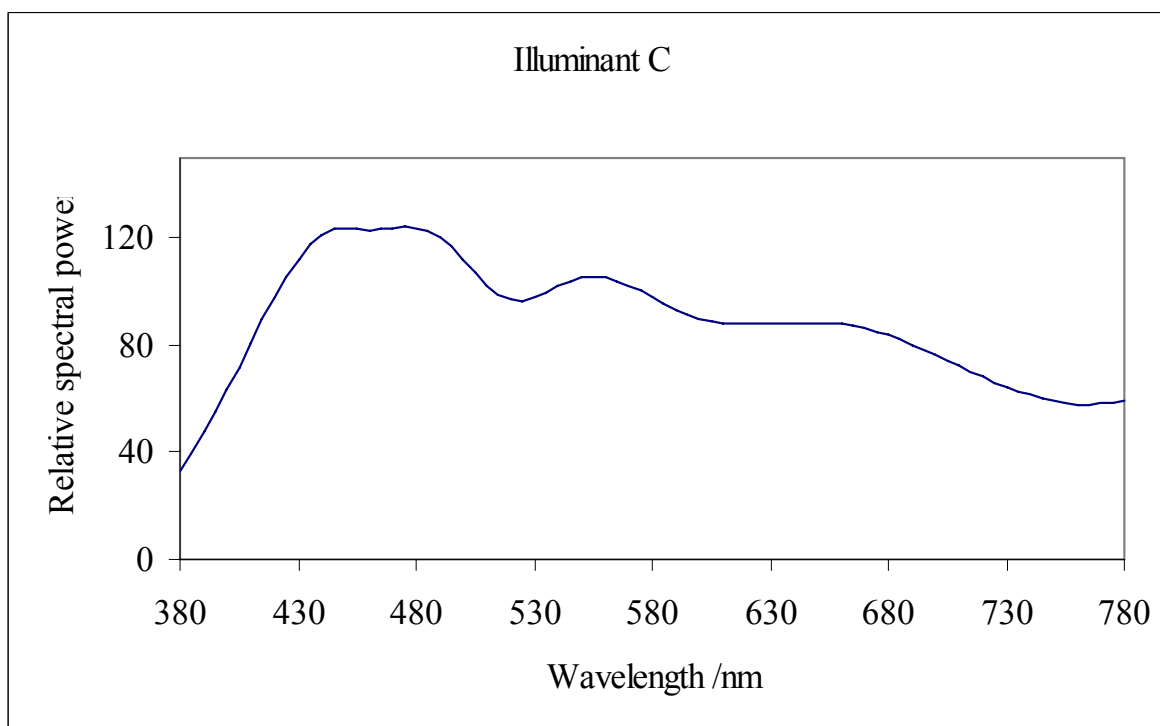
Paper measurement standards often recommend Standard Illuminants. These are CIE tabulated values [13] representing typical light sources, including A (tungsten incandescent), C (tungsten with a particular blue filter to achieve a colour similar to daylight) and the D series, most popularly D65 (a spectrum typifying northern diffused sunlight).

In CIE semantics, *illuminants* are different from *sources*. Illuminants are prescribed relative spectral power distributions, while sources are real artefacts producing light. Some considerable care is needed to ensure a source behaves similarly to an illuminant.

Section 2.5 described how the definition of the specular gloss unit scale is based on a monochromatic sodium D line source, yet measurement methods usually prescribe a source similar to CIE Illuminant C (and a non-spectrally flat measurement response described in the next section). This leads to a small discrepancy between defined and measured scales.

Illuminant C is based on a tungsten source filtered by two liquid-based filters. The relative spectral power distribution function of Illuminant C is shown in Figure 5.1. Impracticalities of using liquids mean glass filters are usually substituted.

Figure 5.1: Relative spectral power of Illuminant C.



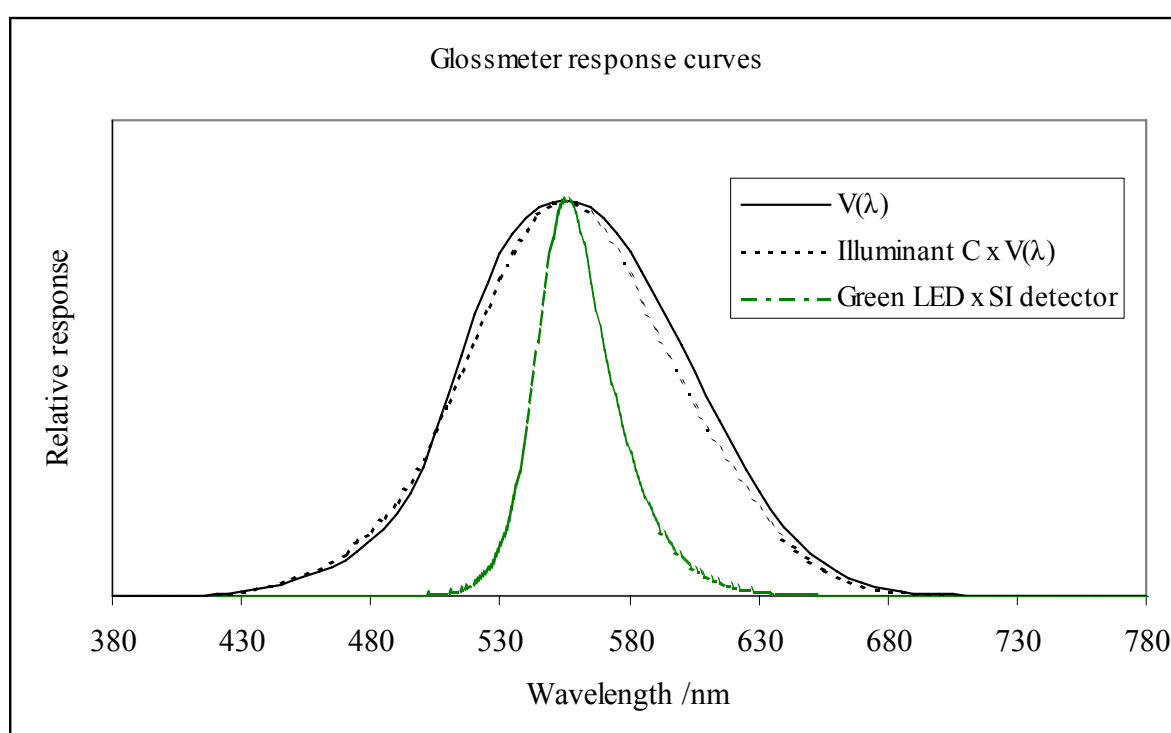
Some instruments use a green LED emitting between 550 and 570 nm - close to the peak of the photopic response function at 555 nm - to define the illuminating radiation rather than correct the detector. Strictly speaking this method will fail to comply with many written standards, although it can be shown that the error introduced will, in most cases, be negligible.

The written standards imply that the source-conversion filter may be mounted in front of the detector instead of between the source and the sample. This is likely to reduce the amount of heat from the source affecting the filter.

5.1.2 Detectors

Gloss measurements relate to human perception, and so the spectral response of detection is equated to the human visual response to light under normal daylight condition. The appropriate internationally recognised function is called the photopic response, or CIE luminous efficiency function $V(\lambda)$. A table of this relative function is widely available [13] and the values are depicted graphically in Figure 5.2.

Figure 5.2: Glossmeter Response Curves



In practice, a filter is used to convert the response of the detector (usually silicon) to $V(\lambda)$.

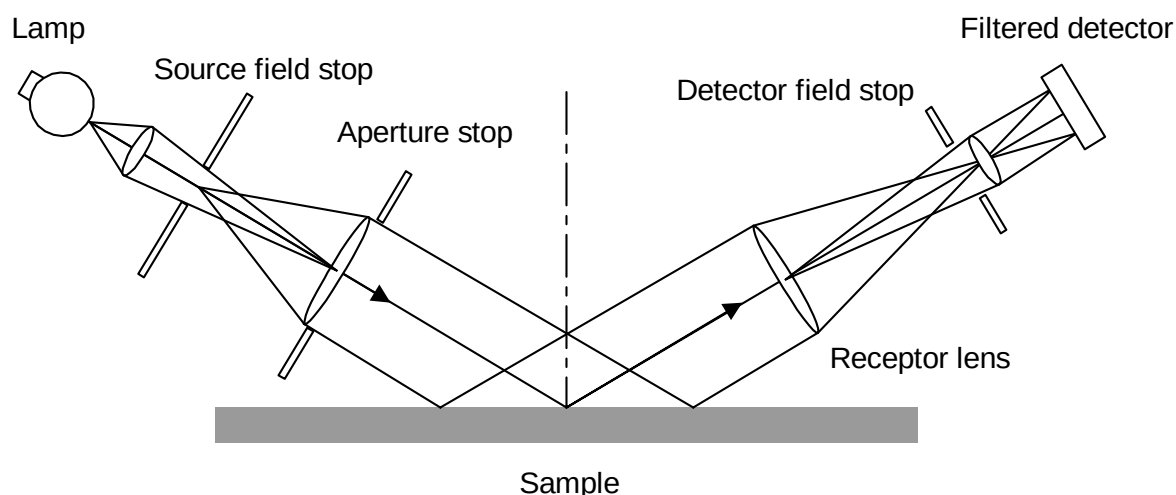
The combination of required source and detector spectral characteristics are given as the broken line in figure 5.2. The narrowest curve in the figure is the spectral power distribution of a green LED multiplied by the response of a typical silicon detector with no additional filtering. Although this shows a considerable departure from the required source/detector combination, as previously suggested, this practical solution may not produce significant errors.

5.2 Types of Instrumentation

5.2.1 Fixed Few Detector/Illuminator

This technology typically has sets of detectors and illuminators mounted as shown in Figure 5.3.

Figure 5.3: A parallel-beam specular reflection instrument.



Using three sets of illuminators and detectors at 20°, 60° and 85° to the sample normal, with the cone angles given in Table 5.1, measurements can be made in accordance with ASTM D523 and many other paper standards.

Table 5.3: Angles of sources and receptors compliant with ASTM D523.

		In plane of measurement /°	Perpendicular to plane of measurement /°
Source image		0.75 ± 0.25	2.5 ± 0.5
Receptor	20°	1.8 ± 0.05	3.6 ± 0.1
Receptor	60°	4.4 ± 0.1	11.7 ± 0.2
Receptor	85°	4.0 ± 0.3	6.0 ± 0.3
Axes of incident and reflected beams should be within $\pm 0.1^\circ$ of nominal value			

Some instruments use a second detector adjacent to the lamp to account for variations in output, though most commonly, the scale is checked with an initial measurement made on a sample of known gloss. This “checking” is described in greater detail in Section 6.5.

This form of instrumentation may be battery powered, with no moving parts, and thus can be extremely portable. Some units can only measure specular gloss at one angle, while others contain optics to measure at up to three angles.

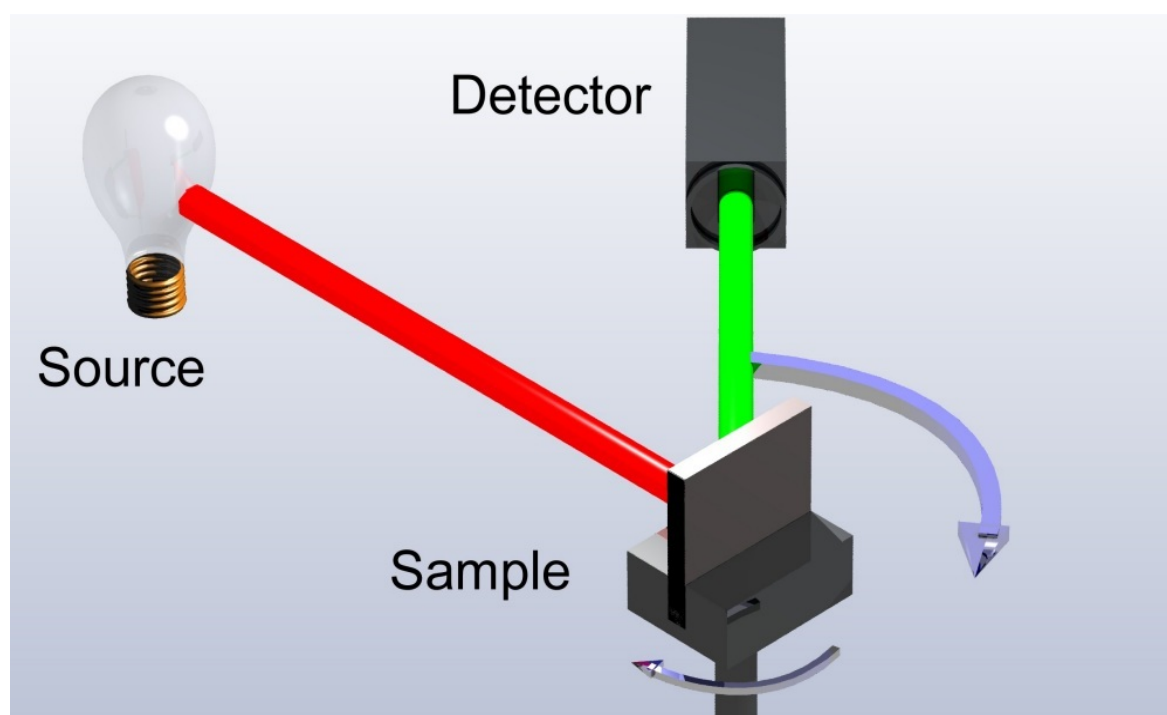
In principle, a rig of this type could be used to measure contrast gloss or lustre, though we are not aware of any commercial instrumentation doing this. Readers should be warned to check

the function of all instrumentation carefully. There is at least one instrument on the market called a 'lustre meter' that actually measures 60° specular gloss, rather than lustre as defined by Hunter and Harold [1].

5.2.2 Mobile Single Detector/Illuminator (Goniometer)

A more flexible and complex version of the above class of instrument is the goniometer. A goniometer fitted with an eye response detector may be called a goniophotometer (GP). Until recently GPs tended to be relatively expensive research instruments, typically used by NMIs to realise their scales [11]. Recent advances in microprocessors and robotics have meant that smaller, affordable GPs are becoming available for industrial use. A typical GP rig is illustrated in Figure 5.4.

Figure 5.4: A goniometer



As the lamp is generally the most fragile component in a GP, it is kept fixed while the sample and detector are moved. The illuminating beam (shown in red) falls on a rotating sample. An arm rotates the detector independently about the sample front surface centre. GPs are often fitted with either a detector-stabilised source, or a secondary monitor to deal with source drift throughout what can be a lengthy measurement.

For goniometers capable of generating values as a function of wavelength, the position of the wavelength-selecting component can be critical. Some place a monochromator between the source and sample to reduce the heating effect of the source on the sample, and reduce stray light. In the case of gloss measurements a broadband detector is more commonly used. Filters to convert the source and detector combination to the required Illuminant C/Photopic response function are placed directly in front of the detector. Where this wavelength selector is placed will be significant if the sample fluoresces.

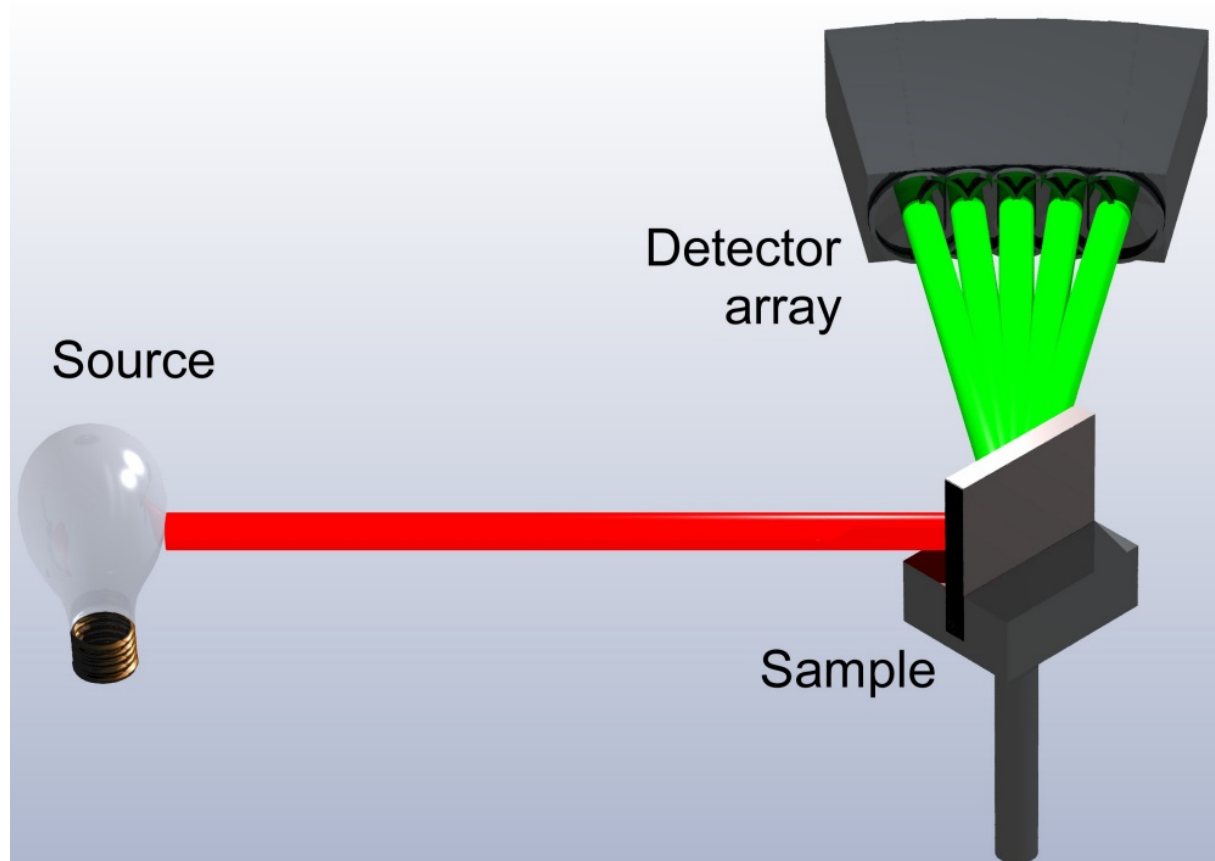
When changing measurement geometry to comply with paper standards, not only the principle axes, but also the illumination and collection cones, must be changed. This is not always simple to automate if results at more than one angle are required.

An instrument with the flexibility afforded by a GP will, with care, be capable of generating values for all types of gloss previously discussed, in addition to other optical properties such as transmittance, haze and (through summation of many results) diffuse reflectance.

5.2.3 Multi Detector Array

Fast developments in consumer technology have brought about the possibility of using inexpensive, speedy imaging methods to speed up the laborious serial function of goniometers with a fast parallel approach. An overview of an array system is shown in Figure 5.5.

Figure 5.5: A multi detector array instrument.



The light source for this type of device is usually fixed, and the detector is a linear (1D) or 2D photodiode array. By way of example, one commercial instrument affords angular resolution of about 0.05° over a $\pm 6^\circ$ range using 128 detectors. Another instrument uses a special type of mirror to translate a wide angular range to a linear detector array.

Digital cameras are also used in this form of instrumentation. These enable 2D images to be used that can increase the width of the measured area, improving quality by taking an average of a larger area. Care needs to be taken that the camera is set correctly, for example that

automatic functions such as white balance, iris and focus do not alter between calibration and measurement.

This instrumentation can use image processing to analyse spread functions of the specular beam to give values for all types of gloss and other visual aspects such as *orange peel*. Work in the Swedish paper industry has developed a so-called ‘Reflection Vector Map’ [20].

5.3 How Results Vary With Time

All measurements vary with time.

5.3.1 Over Short Time Periods

Here we are considering durations typically seconds, the actual duration relating inversely to the square of the intensity of light. As light is composed of small packets of energy (photons) there is a random element to measured signal, termed ‘statistical noise’. A second noise component originates from spurious thermal or electrical currents generated in the detector. Light measurements are a compromise between what is considered to be a reasonable sample time, and the resultant proportion of random noise to (broadly) stable ‘signal’. A simple test is to check the repeat of a measurement. Differences in results from successive measurements made under identical conditions are likely to be due to this statistical noise, and can be used to decide whether the sampling time is sufficiently long, or to indicate some of the uncertainty in the result (the concept of uncertainty is dealt with in greater detail in Section 6).

5.3.2 Over Minutes

Components warm. This can cause a short-term drift which will eventually stabilise - the detector response and filter transmittance are most susceptible. Thus the mean of a number of repeated measurements may differ considerably from the first measurement made using the instrument immediately after switch on. If the system is not temperature regulated, fluctuations in laboratory temperature may also influence results.

5.3.3 Over Longer Time Periods

Over months, and years of use, system response may drift considerably. At risk particularly are lamps, which can increase or decrease in output and change colour. For incandescent tungsten lamps as the filament evaporates the thinner filament burns hotter and the glass envelope becomes blackened with deposition of tungsten. In some environments, dirt and dust can coat optics reducing response and increasing stray light. Calibration standards can become dirty and affect the scale. Sections 6.5.8 and 7.2 deal with the latter point.

How Accurate are Gloss Measurements?

6

IN THIS CHAPTER

- What is accuracy?
- What is uncertainty?
- What is error?
- What is traceability?
- What is inter-instrument agreement?
- Managing errors and uncertainties in gloss measurements
 - » Instrumental traceability
 - » Instrumental calibration
 - » Calibration interval
 - » Measurement repeatability
 - » Instrumental geometry
 - » Scale linearity
 - » System polarisation response
 - » Angular resolution
 - » Operator
 - » Servicing
 - » Sample curvature
 - » Sample orientation
 - » Sample fluorescence
 - » Reproducibility
 - » Environment

How 'good' results are depends on instrumentation and experimental method.

6.1 What is Accuracy?

Accuracy is the closeness of a measured result to the true value of the measured quantity. This is a simple concept, but impractical and of limited use. Were the inaccuracy of measurement always the same (in magnitude and sign), this number would be termed an error and could be corrected for. With real measurements, the accuracy is much more likely to vary (by an amount called 'uncertainty'), when measuring different, or even the same sample under identical, or different conditions. For this reason, uncertainty and error are much more tangible quantities to use. These will now be described in more detail.

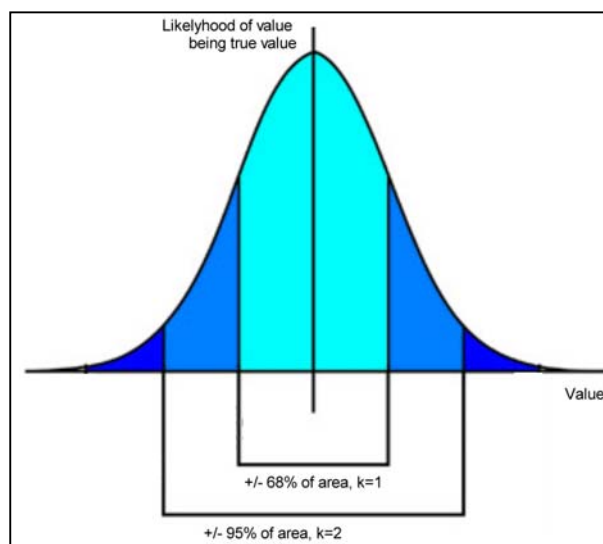
6.2 What is Uncertainty?

Stating that a sample measures 29.5 SGU, and thus passes a requirement to be less than 30 SGU, may be questionable if there is only 60% confidence that the result is between 24.5 and 34.5 SGU. With any measured value, there is an associated uncertainty.

NPL Best Practice Guide 11 [21] deals with uncertainty in a very palatable fashion, describing it as 'a qualification of the doubt about the measured result'.

The standardised format for specifying uncertainty [22] is to describe the relative probability of a range of values being the true value using a spread function modelled by a bell-shaped Gaussian, or normal distribution, function (shown in Figure 6.1). The most likely value (that usually quoted) is at the peak, and the width of the function relates to the measurement uncertainty – a widely spread function indicates a high uncertainty.

Figure 6.1: Gaussian distribution used to describe the standard uncertainty in a result with 68% and 95% confidence areas annotated.



The statement of uncertainty needs to be accompanied by a confidence level which is frequently chosen to be 95% equating to a statistical 2σ level, also expressed as $k = 2$. A confidence level of $k = 2$ means that there is an estimated 95% probability that the true value lies within $\pm x$ of the measured value. The area of the curve between $\pm x$ in Figure 6.1) is 95% of the total area under the curve. The lower uncertainty of 1σ , or $k = 1$ level corresponding to a 68% confidence is sometimes used.

Uncertainties fall into two classes: those that can be calculated from repeat measurements by statistical techniques, and those that are not so treated. The former are often referred to as random, or type A uncertainties, while the latter are called systematic or Type B.

The standard method to combine several evaluated components of uncertainty into an overall uncertainty value is to *take the square root of the sum of the squares of the individual uncertainty contributions*. This assumes that all contributions act independently; another approach is required if any of the contributions are correlated. The details are beyond the scope of this report but are well documented [22], and reasonably simple to implement.

6.3 What is Error?

Error is defined as the difference between the true value and the measured value [21]. Some errors quantified by tests may be corrected for, though it is important to account for the uncertainty the tests themselves add to the measurement.

6.4 What is Traceability?

Quality systems that include measurement processes invariably state that measurements should be traceable to the National Measurement System (NMS). What this means is that an auditor should be able to see how measurement scales of shop floor instrumentation trace through to scales kept at National Measurement Institutes (NMIs). Presentation of a calibrated artefact and its certificate of compliance or calibration together with an operational procedure with estimates of measurement uncertainty usually demonstrate traceability. Without this traceability, it is impossible to know if an instrument is giving the 'right' results. Most instrumentation drifts in time, and whilst it is possible to check for drift with a 'stable' artefact, there is no confidence in the artefact's stability without an independent evaluation. The NMS, with its chain of calibrated artefacts, provides a steady benchmark upon which to base such measurements.

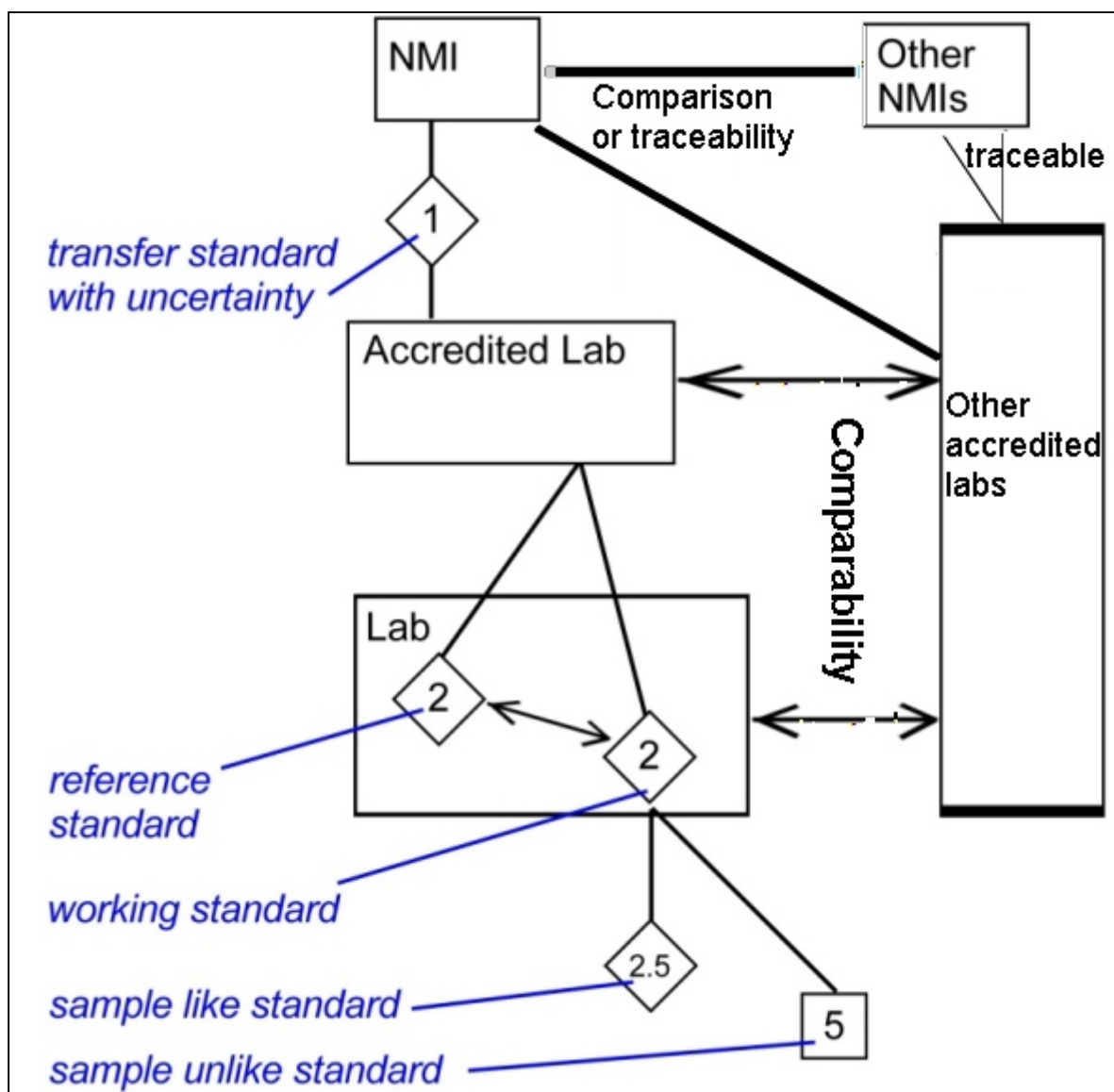
This system of traceability is reinforced internationally through comparisons between NMIs. In this way any biases between national scales can be identified and taken account of, allowing customers in different countries to rely upon the acceptance of their measurements elsewhere.

NMIs are not set up to do simple, repetitive measurements cheaply. Instead, accredited laboratories, whose measurements are traceable to the NMI, generally do these. The accreditation of such laboratories is carried out by an impartial agency - in the UK by the United Kingdom Accreditation Service (UKAS).

A chain of calibrated items – called transfer standards - which can be meters or samples, provides a traceable measurement scale.

The calibration chain illustrated in Figure 6.2 shows how measurement uncertainty is inherited from previous stages in the chain, and added to at each stage. Uncertainty therefore increases with distance in the chain from the NMI. For this reason, some customers spurn the use of cheaper UKAS accredited labs for the less uncertain results an NMI can provide. In the UK it is presently the case that some UK agencies (listed in Section 14) will provide measurements that claim traceability to NMIs, but none of these are UKAS accredited.

Figure 6.2: Traceability Chain



Links with other NMIs enable a degree of comparability between international measurements - designated 'comparability' in the figure. One laboratory in Figure 6.2 is shown to use a system of reference and working standards. Although not illustrated, other labs may also use this system. The working standard is used to regularly calibrate the instrument. The reference standard (very similar in performance to the working standard) is kept in an ideal

environment and brought out only occasionally to check if the working standard has changed. Regular use and recalibration of standards increases the effects of age which can be costly. This common, highly recommended practice can extend the recalibration period of reference standards and increase confidence in results. Figure 6.2 is a simplification. In reality there can be many more links to the chain, and the chains below the ‘other NMIs’ are just as complicated as the one shown on the left.

Measurement scales occasionally change. In 1990 the scale of temperature was redefined [23], leading to a change in the measured value of the boiling point of water of 25 mK. Although few people would be troubled by the fact that a new thermometer would measure boiling water to be 99.975 °C as compared to previous measurements, this is actually more than five times greater than the uncertainty with which the temperature of boiling water has been measured regularly.

When they (infrequently) occur, changes in optical radiation measurement scales have more impact on users than do similar changes in temperature scales. This is because the difference between the uncertainties achievable in, and required by, industry and those at an NMI are much smaller for optical measurements. Indeed, about 50% of customers for NPL optical radiation measurements are limited in the uncertainty they can achieve by the uncertainty available from NPL [24]. In 1990, the diffuse reflectance scale dropped by about 0.4% - an amount equivalent to the uncertainty usually given in NPL certificates for these measurements. Changing this scale caused concern for the providers of white road markings, as paint previously passing a requirement to ‘have reflectance no less than 70%’ now failed.

This example is not intended to demolish faith in the National Measurement System. Rather, it is to warn users that uncertainties quoted in certificates are real factors that should be understood, with ramifications to measurements. When scales are changed – not an action undertaken lightly or without good reason – changes are usually within previously stated uncertainty. New scales are also generally *improved* scales with lower uncertainties than their predecessors thanks to advances in the method of scale realisation.

The gloss scale is directly related to the reflectance scale. Thus a 0.4% change in the reflectance scale will cause a 0.4% change in gloss scale. It is normal practice for NPL to inform customers it has dealt with in the last 6 years of a change in scale, and to tell them of the implications to their results.

6.5 What is Inter-Instrument Agreement?

Although a figure for inter-instrument agreement is often quoted in instrumental specifications to demonstrate instrumental accuracy, it is not necessarily an appropriate indicator of instrumental ability. It usually describes how close results will be for two instruments of the same model, measuring the same sample under identical conditions. It is completely distinct from, and smaller than, the arguably more relevant quantities of accuracy or measurement uncertainty.

6.6 Managing Errors and Uncertainties in Gloss Measurements

Errors and uncertainties are caused by the factors listed in table 6.3. Each component may be treated as an error, and thus corrected for, or combined in an overall uncertainty.

Table 6.3: Contributory factors in gloss measurement error and uncertainty

<u>Due to Instrument</u>	<u>Section</u>	<u>Due to Sample</u>	<u>Section</u>
Instrumental Traceability	6.6.1	Cleanliness	7.2
Instrumental Calibration	6.6.2	Reflective Properties	-
Calibration Interval	6.6.3	Absorptive Properties	-
Measurement Repeatability	6.6.4	Curvature	6.6.11
Geometry	6.6.5	Texture (in 2D and 3D)	-
Illumination Type	5.1.1	Orientation (rotation)	6.6.12
Detector Response	5.1.2	Fluorescence	6.6.13
System Polarisation Response	6.6.6	Reproducibility	6.6.14
Linearity in Response	6.6.7	Response to Environment (temperature, humidity)	6.6.15
Angular Resolution	6.6.8		
Operator	6.6.9		
Equipment Service	6.6.10		
Reproducibility	6.6.14		
Response to Environment (temperature, humidity)	6.6.15		

Five commercial specular glossmeters, all different models, were calibrated at NPL at the same time. They all gave similar readings at the level at which they were calibrated (90 SGU), and also at the 0 SGU level. For samples with intermediate values however, *inter-instrument agreement* was not so good - differences of up to 16 SGU were seen between instruments [15].

This illustrates beautifully how anchoring a scale at one point does not validate an instrument for all conditions. The calibration sample was a glass, and the twenty samples subsequently measured included other glasses, paper, ceramics, plastics and painted surfaces. This problem is often described as a *sample induced error*, although the error is as much related to the meter as to the sample. If all the instrumentation were identical in operation, the spread in values would be much smaller.

One can understand why - with a variation of 16 SGU between instruments for some samples – there may be sense in equipping a facility requiring more than one glossmeter with several of the same model. This is a case when the inter-instrument agreement specification (the agreement between instruments of identical model type) will actually be useful. It should, of course, be noted that this approach will only be successful where consistency of measurement is the key requirement.

It also illustrates another important element of calibration. An instrument should be calibrated for the condition for which it is to be used, or there should be some confidence that the calibration is valid for the range of samples to be measured.

The remainder of this section discusses some of the contributory factors listed in table 6.3.

6.6.1 Instrumental Traceability

The concept and practicalities of traceability have been dealt with in Section 6.4. Although traceability ‘anchors’ a scale, there are a couple of key points:

- Values for traceable calibrated artefacts have an associated uncertainty, which adds to the full uncertainty of any result.
- Calibration standards can age, particularly those for gloss due to a building up of surface contamination, so need to be recalibrated/checked regularly.
- The anchoring of a scale through calibration is very sample/condition dependant. Measurements made under different conditions (for example temperatures or humidity), of samples with different properties (related to many other points in this section), or even by a different operator will add uncertainty and error.

6.6.2 Instrumental Calibration

Calibration is the anchoring of a scale by reference to a known value. Most commercial glossmeters are sold with a calibration plaque at the high gloss level (~95 SGU). When this is used, one of three things can occur:

- A ratio is found of the value of the plaque (stored in the instrument) to the calibration reading and used to scale all subsequent values. (True calibration.)
- The user adjusts the reading displayed to match the calibration value. (True calibration.)
- The instrument checks whether the measured value is within a certain range of the (stored) calibrated value, and will only permit further readings if it is. (A calibration *check*).

6.6.3 Calibration Interval

Calibrations are expensive and can cause down-time. Setting a calibration interval is a risky business. NPL strongly recommend the use of reference and working standards (mentioned in Section 6.4) to check that working standards regularly used are not aging faster than expected, though there is no way of checking the reference standard’s stability unless a higher level standard is used (which may also age). A good approach is to have reasonably short intervals (months) between calibrations initially, and increase times – perhaps by a factor of two each time, until the change in value between recalibrations is significant. Another commonly used approach is to have two sets of reference standards calibrated alternately, and checked against each other.

6.6.4 Measurement Repeatability

As previously mentioned (section 5.3.1), due to the particulate nature of light, light measurements contain statistical noise. Longer time measurements give less noisy results and examining the spread in a number of repeat measurements can indicate the noise component. The techniques for determining and reporting this so-called Type A uncertainty contribution are well documented [21]. If (say) 10 repeats were used to evaluate the Type A uncertainty contribution, to achieve the same uncertainty in subsequent results, 10 repeat measurements

will need to be made to achieve the same uncertainty in future results. That said, statistical methods could be used to estimate the increase in statistical uncertainty with a decrease in the number of repeats.

6.6.5 Instrumental Geometry

Some work has been done [25] to show that whilst the tolerances on gloss measurement geometries are tight, they are perhaps not tight enough for all circumstances. For the 20° geometry, the tolerances on incident angles can lead to changes in measured value of up to 5 SGU, while for 60° and 85° the variation can be less – typically less than or about 1 SGU. The most sensitive types of sample are painted ones.

6.6.6 Scale Linearity

A mathematical model of the non-linearity of an instrument's response can be used to correct subsequent results. The non-linearity of glossmeters is complicated as there are so many factors involved. A set of gloss standards which are measured to have equal intervals on one instrument may have very irregularly spaced results on a second instrument due to sample based errors, for example, changes to the spread of the gloss component with angle about the specular angle.

6.6.7 System Polarisation Response

The Fresnel equations previously showed how specularly reflected light is polarised with a maximum polarisation occurring at about 60°, with the actual angle sample dependant. This polarisation may be detected with different efficiency by different instruments depending on the light source, optics and detector. An initial investigation can be made of detector polarisation sensitivity by rotating a polarised filter placed before it, as it is illuminated by unpolarised light. A constant reading indicates that the detector is polarisation insensitive.

6.6.8 Angular Resolution

This consideration is important in determining spread functions in (for example) assessments of haze using CCD arrays or cameras. The angular resolution should be sufficient to provide adequate assessment. The required limit may be assessed by mathematical means and will vary according to the steepness of the spread function of the sample being assessed.

6.6.9 Operator

Operators do not always follow procedures identically. There is a potential error associated with the operator's interpretation of a procedure, or the way he/she gather and use results.

6.6.10 Servicing

If an instrument is serviced, its performance may change significantly – for example following the replacement of a bulb or cleaning of optics. Care should be taken to monitor such changes. It is prudent to make some measurements before a service engineer touches an instrument for comparison with further measurements made afterwards. The same is true for recalibration.

6.6.11 Sample Curvature

Sample curvature is a major issue in practical gloss measurements. Most methods involve the measurement of flat samples, and any curvature in samples will introduce a sample error. NPL has developed a method for measuring gloss of curved surfaces [26]. Application of some geometry using values for the meter acceptance angle, sample radius of curvature, and source beam radius will evaluate corrections to describe experimental performance.

Generally:

- The gentler the curve, the nearer the measured to the true value.
- Better performance occurs with reduced spot size.
- A correction evaluated for one sample type will be valid for another sample of identical shape but different finish.
- A small area gloss meter (e.g. 1.2 mm), used parallel to the axis of cylindrical curvature shows no loss of performance when measuring surfaces with a radius of curvature greater than 20 mm.
- Measurements of gloss perpendicular to the axis of cylindrical curvature with a small area gloss meter will not be affected for surfaces with a radius of curvature greater than 100 mm.
- For modelling curved surface gloss, parallel, uniform beam optics is essential.

Curved surfaces gloss assessment is a trade off between:

- using a small area of measurement to reduce curvature effects,
- the resultant poorer uniformity and collimation of beam, and the increased noise of a measurement with less light.

6.6.12 Sample Orientation

As mentioned previously, as a sample is rotated its glossiness may change. This is a simple property to check, and it is *always* good practice to indicate the direction of illumination by a label on the sample, whether an effect is seen or not.

6.6.13 Sample Fluorescence

Fluorescence is the re-emittance of light at lower energy than that incident (the difference in energy being lost as heat). This can cause problems with measurements since it effectively changes the response of the detector, or the colour of the illuminant.

A practical, although not particularly quantitative, method to detect sample fluorescence is to view the sample under ultraviolet radiation (a low pressure mercury source with a filter absorbing above 380 nm is particularly effective). If the sample appears significantly different from a non-fluorescing sample of the same colour under normal light, it is likely fluorescence is present.

6.6.14 Reproducibility

If a measurement is repeated on the same sample and same instrument following a repositioning or realignment, of the sample or optical set-up, often on a different day, there is often an additional error due to reproducibility. This differs from the statistical based uncertainty considered in **repeatability** and incorporates such things as operator variability, sample uniformity etc.

6.6.15 Environment

In order to find how samples or meters are affected by environment it is necessary to make measurements over a range of conditions and see if there is any dependency relating to environment. There will be uncertainties present in this determination, both in the gloss measurements (relating to the factors listed above), and in the determination of the environmental parameters (such as temperature and humidity).

Calibration Artefacts

7

IN THIS CHAPTER

- Standards available
- Storing, cleaning & maintaining standards

7.1 Standards Available

The most commonly used gloss standards are made of polished glass.

The most obvious option is to use BaK50, an optical quality barium crown glass since it has high chemical and mechanical durability and the specified refractive index for the sodium D line of 1.5677. This was the approach used by NIST when they developed a primary standard [27]. However this may be considered an unnecessarily expensive solution for most users.

Transparent (known as white) glass, typically with a refractive index of 1.52, is often used in commercial calibration plaques. Use of white glass may be problematical as reflections from the bottom surface can affect results. A common solution to this is to paint all but the working surface of the standard (back and sides) with black paint, though this should ideally be of the same refractive index as the glass or light will be reflected at the glass-paint interface. An alternative solution is to engineer the sample into a wedge with the back surface of the glass non-parallel to the working face. The angle required between surfaces will depend on the angle of measurement [10].

Black glass does not suffer from the back surface reflection issues. However, a degree of antireflection surface has been reported as building up on the surface of black glass almost immediately after polishing [28]. A recommendation has been made that calibration should take place several months after polishing.

The above samples have high gloss with 60° values above 70 SGU. Semi-gloss standards come in a variety of forms, which include glazed ceramic tiles, porcelain-enamelled steel and acid-etched glass. Ground or sand-blasted glass has a reflectance profile that is different to the other types of standard, and is not suitable for evaluating geometric adjustments (such as receptor field stops).

Semi-gloss standards are more susceptible to change in value with heavy usage than full gloss standards, so should be used with care. They are also harder to clean, and it is harder to assess visually the efficiency of the cleaning process.

Samples comprising coated card are also available from Munsell and NCS. Munsell make painted card standards which are sold in so-called 'tolerance sets'. They are custom made to suit a range of up to three gloss levels and six colorimetric levels. NCS (Natural Color Systems, Sweden) also make up custom sets of standards to order.

An indicative list of suppliers of gloss artefacts, calibrated and uncalibrated, are listed in Section 14.

7.2 Storing, Cleaning and Maintaining Standards

Experience has shown that possibly the worst means of storing glass and ceramic standards is to wrap them in paper or plastic. The wrapping absorbs atmospheric pollutants and within only a few weeks redeposits them on the standard in the form of a dirty sheen.

Standards are often sold with fairly airtight cloth-lined boxes which are reasonably successful in protecting them. Boxes allowing a material to be in contact with the standard working surface run the risk of redepositing pollutants as described above.

The NPL practice of storing gloss standards in an airtight desiccator has kept their performance stable over several years. That said, these standards are not as intensively used as those in many industrial applications, and the laboratories they are used in, whilst not clinically clean, are cleaner than some industrial environments.

There is anecdotal evidence that cleaning standards has varied success. The black silica standards NPL uses have a good record of returning to original values after cleaning to provide consistent results (unchanged within the measurement uncertainty over ten years). Other types of standard have not performed so well. For white-glass, black-paint-backed standards, care must be taken that the cleaning method does not degrade the paint.

The NPL cleaning method is as follows.

- 1 Make up a solution of fluorophor-free detergent in de-ionised water. Totally immerse the standard in this solution for 15 minutes.
- 2 Gently rub the surface of the sample with the solution using a lint free cloth, removing any dirt marks.
- 3 From now on ensure that fingers do not touch the working face of the sample. It is preferable to wear (rubber) gloves.
- 4 Rinse the sample under running de-ionised water for at least two minutes to remove any detergent residue. The water should ‘bead up’ on the sample surface.
- 5 Blow-dry the sample with filtered air.
- 6 Squirt pure (95%) ethanol over the working face. Blow dry with clean air so that the alcohol drying ‘front’ carries any dirt along with it away from the centre.
- 7 Closely examine the working face under a single tungsten source obliquely illuminating the sample. Take care not to mistake any internal structure of the sample for surface blemishes. Any dust particles remaining can be gently brushed away with a fine art paintbrush. If surface blemishes remain which may jeopardise measurements, it is unfortunately necessary to return to the beginning of the cleaning procedure.

- 8 Dry the sample. Carefully place it about 50 mm below a 100 W infrared lamp for 10 minutes. Then place in a desiccator or humidity cabinet for at least 24 hours prior to measurement.

Work at NRC Canada has shown [28] that even the best kept standards become contaminated in time and can show changes in refractive index of between 0.3 and 0.5% over three years, equating to a change of about 1 or 2 SGU at 20° and 60° respectively. NRC went on to show how repolishing the surface with cerium oxide returned the standards to their original condition and specular gloss values.

NPL Gloss Measurements

8

IN THIS CHAPTER

- Measurements of customers' artefacts
- International intercomparisons

NPL Gloss Measurements

The NPL owns about 10 different instruments representing the three types of instrument listed in Section 4.1 and capable of performing all forms of gloss measurement with determined uncertainties. The majority of work for customers to date has been measurement of specular gloss according to ASTM D523, the scale for which is realised on the NPL National Reference Reflectometer (NRR) [15]. This instrument is a large spectro-goniometer, with results verified by international intercomparisons.

8.1 Measurements of Customers' Artefacts

The NPL has a reputation for speedy and competent calibration of customers' gloss standards and instrumentation. The contractual turnaround time is usually 4 weeks, though in practice, time between receipt of items and their dispatch after calibration is always less than that. We have performed some quite involved measurements - with results before and after cleaning - in only three days.

A major cost of measurements on the NRR is setting it up; following that, there is a fair amount of automation. This means that there is a reasonable cost discount for measurement of multiple samples and angles.

A smaller commercial bench glossmeter does 'like with like' comparisons between standards calibrated on the NRR, and new 'customer' standards for the three specular geometries 20°, 60° and 85°. If customer standards differ in material from the standards NPL owns, we would be reluctant to use the bench instrument, and use the NRR instead, or apply large uncertainties to the results. Typical measurement uncertainties are 1.5 SGU for 100 SGU samples, and about twice that for 50 SGU samples.

NPL calibration results are normally presented in certificate form, including a description of measurement method and an uncertainty statement, though on request we have written letters stating that measured values comply with specified requirements.

8.2 International Intercomparisons

The major function of a National Measurement Institute (NMI) is to maintain scales of measurement. National scale realisations are usually achieved with complex apparatus with uncertainties that are well understood. A critical part of validating such instrumentation and its use is to conduct international intercomparisons with other NMIs.

For gloss, an international intercomparison comparing the gloss scales of NPL, BAM and NRC [15] was completed in 1998. Eight samples were used to establish that the three partners' scales agreed within their quoted uncertainties.

Glossary of Terms

9

Glossary of Terms

Definitions for commonly occurring terms in gloss measurements are given in this section. Those definitions marked with * are taken from ASTM E284 (2004), a Standard Terminology of Appearance.

Term	Meaning	Section
Absence of Bloom	Hazy, milky appearance in reflection near specular angle	2.3
Absence of Surface Texture	Perception of surface non-uniformity	2.3
Bloom*	The scattering of light in directions near the specular angle of reflection by a deposit on or exudation from a specimen	2.3
Contrast Gloss	Ratio of specularly reflected to diffusely reflected light = lustre (some definitions) and haze (some definitions)	2.3
Distinctness of Image*	Aspect of gloss characterized by the sharpness of images of objects produced by reflection at a surface	2.3
BRDF	Bidirectional Reflectance Distribution Function (or Factor if it is a single number quoted for a single geometry). For definition see appropriate section	2.8
Error	Difference between the true value and the measured value	6.3
Gloss	The attribute of surfaces that causes them to have shiny or lustrous, metallic appearance	2.1
Glossmeter	Instrument for measuring gloss	5
Haze	An alternative name for contrast gloss that compares specular with diffusely reflected light. Take care – Haze is also used to describe diffuse transmittance (for example in ASTM D1003)	2.3
Illuminant C	Spectral power distribution definition for a daylight simulator. Not spectrally identical to daylight, but similar	5.1.1
Lustre*	The appearance characteristic of a surface that reflects more in some directions than it does in other directions, but not of such high gloss as to form clear mirror images	2.3
Matt finish	A finish without a glossy component of reflectance. There is an empirical mathematical model for this	

NMI	National Measurement Institute (such as NPL, NIST, BAM etc). These institutes are responsible for maintaining and disseminating units of measurement	6.4
NMS	National Measurement System: comprising a chain of traceable measurements connecting to a national scale	6.4
Orange Peel	A surface finish unevenness on the millimetre scale	2.3
Photopic Response	Relative spectral response to light representative of that of the human eye at daylight illumination levels	
Refractive Index	The ratio of light velocity in a vacuum to its velocity in the transmitting medium. Reflections occur at interfaces between volumes of different refractive index	2.5
Specular Gloss	Ratio of specularly reflected light to incident light	2.3
SGU	Specular Gloss Unit. A scale based on the performance of a glass with refractive index 1.567 which, by definition, has a value of 100 SGU at any angle	2.5
Sheen	Specular gloss at grazing angles of incidence and viewing. The term derives from the fact that surfaces seemingly matt can appear glossy at these angles	2.3
Uncertainty	A qualification of the doubt about the measured result	6.2

Further Reading

10

Further Reading

For the reader who would like to know more about aspects discussed in this guide the article and books listed below contain further detailed information.

- 1 RESEARCH NOTE: *Evaluation of the Attribute of Appearance Called Gloss*, CIE Journal, Vol. 5, No. 2, pp41-56, (1986)
- 2 BOOK: R. S. Hunter, R. W. Harold, *The Measurement of Appearance*, Hunter Associates Laboratory, Virginia, USA, ISBN 0471830062, (1987)
- 3 BOOK: V. G. W. Harrison, *Definition and Measurement of Gloss*, Cambridge (1945), W. Heffer & Sons. (Out of Print)

Written Gloss Standards

11

IN THIS CHAPTER

- General
- Paint
- Plastics
- Metals
- Paper
- Furniture
- Floor-polish
- Ceramics
- Fabrics
- Standard geometric conditions

11.1 General

ASTM D523 1999 (USA)

Test method for specular gloss

The principal ASTM specular gloss standard. Very similar to ISO 2813.

ASTM D3928 1998 (USA)

Test method for evaluation of gloss or sheen uniformity

ASTM D4039 1999 (USA)

Test method for reflection haze of high-gloss surfaces

ASTM D4449 1999 (USA)

Test method for visual evaluation of gloss differences between surfaces of similar appearance

ASTM D5767 1999 (USA)

Test methods for instrumental measurement of distinctness of image gloss of coating surfaces

ASTM E430 1997 (2003) (USA)

Test method for measurement of gloss of high-gloss surfaces by goniophotometry

MFT 30-064 (South Africa)

Local version of ASTM D523

JIS Z8741 1997 (JAPAN)

Method of measurement for specular glossiness

11.2 Paint

ISO 2813 2000 (International)

Paints and varnishes - determination of specular gloss of non-metallic paint films at 20°, 60° and 85°

The principal ISO specular gloss standard. Very similar to ASTM D523.

The following are technically similar to ISO 2813:

BS 3900: Part D5 1995 (UK)

Methods of test for paints - optical tests on paint films - measurement of specular gloss of non-metallic paint films at 20°, 60° and 85°

DIN 67530 1982 (Germany)

Reflectometer as a means for assessing the specular gloss of smooth painted and plastic surfaces

NFT 30-064 1999 (France)

Paints - measurement of specular gloss at 20, 60 and 85°.

AS 1580 MTD 602.2 1996 (Australia)

Paints and related materials, methods of test – introduction and list of methods

JIS Z8741 1997 (Japan)

Specular glossiness – Method of measurement

SS 18 41 84 1982 (Sweden)

Paints and varnishes - measurement of specular gloss of non-metallic paint films at 20, 60 & 85°

11.3 Plastics

BS 2782: Pt 5, Method 520A 1992

Methods of testing plastics - optical and colour properties, weathering - determination of specular gloss

Similar to ISO 2813.

ASTM D2457 1990

Test Method for Specular Gloss of Plastic Films and Solid Plastics

Specifies the primary standard as a perfect mirror with a defined gloss value of 1000. 20°, 60° and 45°; the 45° method is as ASTM C346 for ceramics.

11.4 Metals

BS6161: Part 12 1987

Methods of test for anodic oxidation coatings on aluminium and its alloys - measurement of specular reflectance and specular gloss at angles of 20°, 45°, 60° or 85°

Ref. Std BS 3900: Part D5 (1980); technically equivalent to ISO 7668; replaces BS 1615:1972. At 45°, dimensions of source image and receptor aperture are as for 60°. Squares with sides equal to the shorter sides of the rectangles are also recommended. Alternatively, total reflection in a 45° prism is used as a reference; source image and receptor aperture are then circular, both with angular diameter $3.44^\circ \pm 0.23^\circ$ (1.5 mm $\pm$ 0.1 mm at 25.4 mm focal length) .

ISO 7668 1986

Anodized aluminium and aluminium alloys - measurement of specular reflectance and specular gloss at angles of 20°, 45°, 60° or 85°

ISO 5190

Anodizing of aluminium and its alloys - evaluation of uniformity of appearance of architectural anodic finishes - determination of diffuse reflectance and specular gloss

ECCA T2 (European Coil Coating Association)

Specular gloss at 60°.

11.5 Paper

DIN 54502 1992

Testing of paper and board; reflectometer as means for gloss Assessment of paper and board

ASTM D1223 1998

Test method for specular gloss of paper and paperboard at 75°

Has unusual converging beam geometry. Specifies the primary standard as black glass of refractive index 1.540, not 1.567, at the sodium D-line having a defined gloss value of 100.

ASTM D1834 1995

Test method for 20° specular gloss of waxed paper

Another unusual converging beam geometry, different from the previous one.

TAPPI T480 OM-90 1990 (USA)

Specular gloss of paper and paperboard at 75°

Same text as ASTM D 1223.

TAPPI 653 1990

Specular gloss of waxed paper and paperboard at 20°

Probably the same text as ASTM D 1834.

JIS - Z8142 1993 (Japan)

Testing method for 75° specular gloss.

11.6 Furniture

BS 3962: Part 1 1980

Methods of test for finishes for wooden furniture - assessment of low angle glare by measurement of specular gloss at 85°

Similar to ISO 2813: 1978

11.7 Floor Polish

ASTM D1455 1987

Test method for 60° specular gloss of emulsion floor polish

Ref. std ASTM D 523

11.8 Ceramics

ASTM C346 1987

Test method for 45° specular gloss of ceramic materials

Ref. std ASTM D 523

ASTM C584 1981

Test method for 60° specular gloss of glazed ceramic whitewares and related products

Ref. std ASTM D 523

11.9 Fabrics

BS 3424: Method 31: Part 28 1993

Testing coated fabrics - determination of specular gloss

Draft

11.10 Standard Geometric Conditions

ASTM D523, ISO 2813, BS 3900 and others

		In plane	Out of plane
Source image		$0.75^\circ \pm 0.25^\circ$	$2.5^\circ \pm 0.5^\circ$
Receptor	20°	$1.8^\circ \pm 0.05^\circ$	$3.6^\circ \pm 0.1^\circ$
Receptor	60°	$4.4^\circ \pm 0.1^\circ$	$11.7^\circ \pm 0.2^\circ$
Receptor	85°	$4.0^\circ \pm 0.3^\circ$	$6.0^\circ \pm 0.3^\circ$

ASTM D2457, C346 (plastics, ceramics)

Source image	45°	$1.4^\circ \pm 0.4^\circ$	$3.0^\circ \pm 1.0^\circ$
Receptor		$8.0^\circ \pm 0.1^\circ$	$10.0^\circ \pm 0.2^\circ$

This standard is adopted by *ExxonMobil Chemical* in USA according to their documentation:
(www.exxonmobilpe.com/Public_Files/Polyethylene/Polyethylene/NorthAmerica/Technology_tip_2.pdf)

This states that the value for a ‘perfect mirror’ is 1000, and that sets the value of a mirror at 100 so as to ‘report the percentage value of gloss’, and qualify that ‘compared to competitive values, ExxonMobil Chemical’s values may differ by a factor of 10’.

BS6161 (anodized aluminium)

Source image		$3.44^\circ \pm 0.23^\circ$
Receptor	45°	$3.44^\circ \pm 0.23^\circ$ (circular)

DIN 54 502 (paper)

Source image	$1.0^\circ \pm 0.1^\circ$	$2.5^\circ \pm 0.1^\circ$
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- 4 F. J. J. Clarke and D. J. Parry, *Helmholtz Reciprocity: Its Validity and Application to Reflectometry*, *Lighting. Research and Technology*, **17**, 1-11, (1985)
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For information on optical measurements at NPL:

http://www.npl.co.uk/optical_radiation

For information on measurement of visual properties of materials at NPL:

www.npl.co.uk/optical_radiation/appearance

Agencies Performing Gloss Calibrations & Supplying Artefacts

14

Agencies Performing Gloss Calibrations and Supplying Artefacts

In some instances the NMIs are government owned and operated by private companies. The list of 'test methods' is not exhaustive as many methods are similar. The author apologises for any omissions or errors in this section. Please update him if further information is available.

Country	Argentina	Australia	Canada	Czech Republic	France
Agency	INTI	CSIRO	NRCI	CMI LPM 814	BNM-LNE (1)
NMI or Private company	NMI	NMI	NMI	NMI	NMI
Angle /°	20		20, 60, 85, 45	20, 60, 85	20, 60, 85
Test methods	DIN 67530		ASTM D523 ISO 2813 ISO 7668	ASTM D523 ISO 2813	NFT 30-064
Best Measurement Capability /SGU		Have facilities	0.3	1.5	1.0
Traceability			NRC	NPL	BNM
Contact	www.inti.gov.ar (Spanish)	www.cmit.csiro.au/bruchures/serv/plastic/	http://nims-ienm.nrc-cnrc.gc.ca/calserv/potometry_e.html	www.cmi.cz	www.lne.fr

Country	Germany	Germany	Hungary	Italy	Japan
Agency	BAM	PTB	OMH	IEN	Murakami Color Research Laboratory
NMI or Private company	NMI	NMI	NMI	NMI	Private
Angle /°	20, 60, 85		20, 60, 85		20, 45, 60, 70
Test methods	DIN 67530, ISO 2813	DIN 67530	ISO 2813		ISO, JIS, ASTM, DIN and TAPPI
Best Measurement Capability /SGU	0.3		1.0	1.0	
Traceability	BAM		OMH	IEN	
Contact	www.bam.de/english/service/reference_procedures_media/602en.pdf	www.ptb.de	www.omh.hu	www.iem.it	www.mcri.co.jp

Country	Japan	Japan	Netherlands	Poland	Sweden	Sweden
Agency	Suga	Nippon Denshoku	NMI-VSL	GUM	NCS	SP
NMI or Private company	Private	Private	NMI	NMI	Private	NMI
Angle /°		20, 45, 60, 75, 85	20, 60, 85			20, 60, 85
Test methods					ISO 2813	ISO 2813
Best Measurement Capability /SGU			6.0			1.0
Traceability		Japan Color Research Institute	NRC	BAM		
Contact	www.sugatest.co.jp (Japanese)	www.nippondenshoku.co.jp	www.nmi.nl	radiation@gum.gov.pl	www.ncscolor.com	www.sp.se/eng

Country	UK	UK	UK	UK	UK
Agency	NPL	Sheen Instruments	PRA Coatings Technology Centre	Rhopoint Instruments	Welsh Centre for Printing and Coating
NMI or Private company	NMI	Private	Private	Private	Private
Service or Angle /°	Any	Sell glossmeters		20, 60	
Test methods	Any		ISO 2813, BS 3900-D5		
Best Measurement Capability /SGU	0.3				
Traceability	NPL			BAM	
Contact	www.npl.co.uk/optical_radiation	www.sheeninstruments.com	www.pra.org.uk	www.rhopointinstruments.com	www.swan.ac.uk/printing/pdf/Brochures/measurement.PDF

Country	UK	UK
Agency	Paint Test Equipment	Aerospace Metrology & Electromechanical Calibration Ltd
NMI or Private company	Private	Private
Service or Angle /°	Sell Glossmeters 60 and 60/20	Seeking accreditation
Test methods	ISO-2813	ISO-2813
Best Measurement Capability /SGU	1%	TBA
Traceability	BAM	BAM
Contact	www.paint-test-equipment.com	Met-Cal House, Fisher Street, Newcastle upon Tyne NE6 4LT

Country	USA	USA	USA	USA	USA
Agency	NIST	American Testing Laboratory, Inc.	Collaborative Testing Services, Inc. A comparative measurement scheme	Byk-Gardner	Atlas
NMI or Private company	NMI	Private	Private	Private	Private
Angles /°	20, 60, 85		60, 85, 75	20, 60, 85	
Test methods	ASTM D523, ISO 2813		ASTM D523, TAPPI T480		ASTM D523, E430, DIN 67530, ISO 2813, ISO 7668
Best Measurement Capability /SGU					
Traceability	NIST		n/a	BAM	NPL
Contact	http://slp.nist.gov	www.mytestlab.com	www.collaborativetesting.com	https://byk-gardnerusa.com	www.atlas-mts.com

Country	Sweden	UK	Worldwide
Agency	Natural Color System	DG Colour	Gretag Macbeth
NMI or Private company	Private	Private	Private
Service	Sell paper and card artifacts	Sell Munsell artifacts	Sell Munsell artifacts
Contact	www.ncscolour.com	www.dgcolour.co.uk	www.gretagmacbeth.com

NPL Good Practice Guides

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NPL Good Practice Guides

For an updated version of this list and details on how to obtain copies, visit:

www.npl.co.uk/npl/publications/good_practice

- GPG (001)** Code of practice for the Measurement of Bending in Uniaxial Low Cycle Fatigue Testing
- GPG (002)** Measurement and Analysis of Creep in Plastics
- GPG (003)** Measuring Flow Stress in Hot Asymmetric Compression Tests
- GPG (004)** Calibration and use of EMC Antennas
- GPG (005)** Software in Scientific Instruments
- GPG (006)** UV Embossed Optical Microstructured Surfaces
- GPG (007)** Flexural Strength Testing of Ceramics and Hardmetals
- GPG (009)** The Measurement of Palmqvist Toughness for Hard and Brittle Materials
- GPG (010)** Residual Stress in Polymeric Mouldings
- GPG (011)** A Beginner's Guide to Uncertainty in Measurement
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