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in Colour and Vision

Contents:

- 118/1 Evaluation of the Attribute of Appearance Called Gloss (Reprint)
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Abstracts of CIE Publications prepared within Division 1

CIE 118-1995

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CIE RESEARCH NOTE

EVALUATION OF THE ATTRIBUTE OF APPEARANCE CALLED GLOSS*

Abstract:

This technical report discusses current concept of gloss as an appearance phenomenon and as a measured attribute of materials. First the general attributes of appearance are described, followed by a description of gloss attributes. The interaction of light and materials that is responsible for gloss sensations is briefly covered. Definitions are given terms related to gloss perception and to the light-reflection properties of materials associated with gloss. The general design characteristics of specular glossmeters are described and standard procedures for gloss measurement are tabulated according to gloss-scale geometry and according to country of usage. Material standards for specular-gloss scale calibration are discussed.

Evaluation de l'attribut, nommé ECLAT

Résumé:

Le rapport décrit la position actuelle relative au problème du brillant comme phénomène d'apparence et comme propriété mesurable d'un matériau. On décrit d'abord les traits généraux des phénomènes d'apparence avant de décrire les attributs relatifs au brillant. On expose brièvement les relations entre le rayonnement lumineux et les matériaux, à l'origine des sensations de brillant. On donne des définitions relatives aux termes liés à la perception de brillant et aux propriétés de réflexion des matériaux qui sont en rapport avec le brillant. Les principes des appareils de mesure du brillant spéculaire sont décrits ainsi que les méthodes normalisées de mesure du brillant. Des tableaux présentent les différences entre les méthodes de mesure du point de vue de la géométrie, des échelles de brillant, des domaines d'emploi et des pays. Enfin, on discute l'emploi de matériaux de référence pour l'étalonnage des échelles de brillant spéculaire.

Auswertung des Erscheinungsmerkmals, das GLANZ genannt wird.

Zusammenfassung:

Der Bericht diskutiert die derzeitige Kennzeichnung des Glanzes als ein Wahrnehmungsattribut und als eine messbare Stoffkennzahl. Auf die Beschreibung allgemeiner Wahrnehmungsattribute am Anfang folgt diejenige der Glanzattribute. Die für die Glanzempfindung verantwortliche Wechselwirkung von Licht und Materie ist kurz beschrieben. Die für die Beschreibung der Glanzempfindung und der entsprechenden Reflexionseigenschaften von Materialien erforderlichen Begriffe werden definiert. Die allgemeinen Konstruktionsmerkmale von Geräten für die Messung des gerichteten Glanzes sind beschrieben, und die Standardverfahren für Glanzmessungen sind entsprechend der Geometrie der Glanzskala und des Gebrauchslandes klassifiziert. Ausserdem werden Materialstandards für die Kalibrierung von Skalen für gerichteten Glanz diskutiert.

ACKNOWLEDGEMENTS

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*This CIE Research Note was prepared by TC 2-20, chairman John S. Christie, Jr., Hunter Associates Laboratory Inc., 11495 Sunset Hills Road, Reston, Virginia 22090, USA on behalf of CIE Division 2: Physical Measurement of Light and Radiation.

1 INTRODUCTION

This document identifies the current understanding of the phenomenon known as gloss and describes the current status of its measurement¹. Further work to propose visual scaling experiments and offer recommendations for the development of psychometric gloss scales and to establish correlation between visual evaluations and instrumental measurements, is currently being addressed by CIE TC 2-20.

1.1 What is Appearance?

Appearance can be defined as the aspect of visual experience by which things are recognized. When an observer "sees" something, there are many sources of information from the scene and the objects that he sees. Neural responses are generated that, after being detected, modified, and transmitted by the visual system, are processed in the occipital cortex of the brain. With experience, the observer transforms these multiple sensations into a complex perception.

To establish order in the extremely complex appearance situation, we need to classify the observing condition by which we are seeing things. Three general modes of perception are:

1. The illuminant mode, by which we see an identifiable source of light, such as a lamp.
2. The aperture mode, by which we see simply light without any recognition of a light source or object.
3. The object mode, by which we can identify an object within a visual field and recognize its illumination by some light source.

In this discourse, we consider only the object mode of appearance. The appearance of an object is affected by other aspects of the whole perceptual complex, such as illumination level, light and color contrast, adaptation, etc. These variations in observer conditions are not considered here.

Our perceptions of certain features of objects allow us to characterize them. These perceived characteristics are called attributes of appearance.

Appearance involves color, duration, and extent. In general, one may say that color consists of hue, saturation, and lightness. Duration consists of fluctuation, flicker, sparkle, glitter, scintillation, and movement. Extent consists of size, shape, location, number, texture, glare (for luminous objects), transparency, and gloss (for nonluminous objects).

Gloss is an attribute of secondary importance with respect to the perception of the appearance of an object. Normally, motion, size and color

are the attributes of which, consciously or unconsciously, an observer is first made aware. Nevertheless, the gloss of materials is an important attribute that quite often identifies a major difference between objects. Gloss and color are important, not only because they influence our judgments of the quality of our environment, but because they are involved in the selection of commercial products in which, in addition to beauty, quality, and durability, they are many times linked to acceptability.

In some cases, it is possible to establish an objective method to evaluate the aspect of appearance. This is particularly evident in the case of color for which, based on the Young-Helmholtz trivariance theory, the entire system of colorimetry (the measurement of color) has been developed. The perceptual characteristics of the human observer that are involved in color matches are quantified and standardized by the CIE Standard Observer for color that was developed in 1931 and is widely used all over the world. The color-matching functions $\bar{x}$, $\bar{y}$, $\bar{z}$, of the CIE Standard Observer are psychophysical quantities. That is, they are a numerical expression of a psychological response to a physical stimulus. They are based on a light-mixing experiment that has proven to be scientifically sound in that it can be repeated by a particular observer and reproduced by different observers in different laboratories.

Due to the nature of gloss, a corresponding type of specification has not been quantified or standardized. This is mainly because gloss is dependent on the spatial (geometric) variations of the luminous flux from a source of limited extent, as perceived by the observer after being modified by the object and the surrounding conditions. The development of a standard observer for color was possible because the observer's sensitivity to an independent variable, wavelength, can be reproducibly quantified. No equivalent psychophysical experiment has been devised to produce gloss sensations, perhaps because of the difficulties in reproducing controlled spatial variations of luminous flux that duplicate normal observing conditions. No generally applicable procedure has been developed for relating visual scaling for perception of gloss to numerical specifications. However, some recent experiments should be noted.

Fleischer² devised a gloss apparatus that consists of a rotating wheel with high-gloss and low-gloss portions. Their ratio could be changed to establish visual matches with a wide variety of specimens. Czepluch³ has synthetically generated gloss perceptions by letting the observers look at a different object with each eye. The two objects had no specular reflection, and monocular

viewing created no gloss sensation. The objects were ring systems with different luminosity distributions. O'Donnell⁴ has developed a method for the multidimensional scaling of gloss. A series of visual scaling experiments, using anchored-pair comparisons, were made on prepared gray, black, and white paint samples. Several multidimensional scaling methods were applied to the results of the visual judgments. Harrison⁵ describes earlier experiments on binocular gloss and luster, together with his and other hypotheses on their causes.

Gloss perceptions probably involve the binocular visual mechanism. This adds yet another difficulty in the task of devising a suitable experiment to provide correlation between the physics of light distribution and the resulting gloss sensation.

1.2 The Attribute of Appearance Called Gloss

Gloss is a psychophysical phenomenon, as is color. Gloss perceptions are associated with the way (with respect to the geometric spatial distribution) that light is reflected by an object, particularly depending on the way light is reflected from the surface of the object in and near the specular direction.

Gloss and other phenomena, such as haze, luster, and translucency, that depend on the geometric spatial distribution of the light reflected or transmitted by the object, are normally perceived independent of color. They may affect or be affected by the perceived color, but may be abstracted from a total visual experience as separate from color. These phenomena are numerous and complex, both as forms of perception and in terms of underlying physical phenomena correlated with those perceptions.

In addition, the influences of illuminating conditions and the background conditions under which gloss judgments are made also have a significant effect on the perceptions. Gloss perception is particularly dependent on the conditions under which the object is illuminated. In very general terms, the greater the diffusion of the incident light, the lower the gloss appearance. In other words, when the directions from which light falls on the object are increased, the ability to differentiate specular and diffuse reflectance diminishes. Therefore, the observer becomes increasingly unable to evaluate the glossiness of the object effectively. The combination of all of these possible variations makes total appearance analysis not only very complex but probably not even useful to attempt. In a given situation, however, it has been possible to identify a limited number of predominant geometric appearance attributes, and

these can sometimes be isolated. For example, in automobile finishes, the most significant attribute is <distinctness-of-image>, whereas in textiles, <contrast gloss or luster> perceptions predominate. In interior wall finishes, variations in <sheen> are considered undesirable in the finished product appearance.

When analyzing the bases for gloss perceptions, one must consider the ways in which a surface reflects light. Gloss is generally associated with specular reflectance at the surfaces of objects. This type of reflection may vary from one surface to another according to the fraction of light reflected in a specific direction, the degree to which light is reflected in various directions relative to the direction of specular reflection, and the change of relative reflectance as the specular angle varies.

In 1936, Hunter⁶ indicated the importance of these variations. His investigations resulted in a description of six different types of gloss which he termed specular gloss, distinctness-of-reflected-image gloss, contrast gloss, absence-of-bloom gloss, sheen, and absence-of-surface-texture gloss. In this paper he states that, while some may choose different names for these characteristics of objects that we may perceive, each of them may be readily and easily demonstrated. Each of these is a different visual perception, and each is best recognized by using different sets of illuminating and viewing conditions. Of course, it is logical to assume that instrumental measurement of these perceptions will similarly require different instrument geometries. It might even be necessary to consider an optical system that duplicates the binocular effect of the human visual system.

1.3 Physical Factors that Contribute to Gloss Perception

A description of the physical factors that contribute to gloss perception is helpful when considering different types of gloss.

Nonselfluminous objects may absorb, scatter, reflect, refract, and/or transmit light which is incident upon them. The amount of light reflected, relative to that refracted into the body of the material, can be calculated by the Fresnel law. Metallic materials reflect and scatter most of the incident light at the air/metal interface. There is little penetration of light beyond that surface. Nonmetallic or dielectric materials generally exhibit much lower surface reflection. Therefore, scattering and absorption within the body of a nonmetal importantly affect its appearance. In this report, we concentrate on the gloss characteristics and on the spatial distribution

of light (geometric characteristics) reflected by nonmetallic objects.

Light that is not reflected at the air/material interface of nonmetals is refracted and transmitted through the medium. If the material contains large numbers of small particles whose index of refraction differs from that of the rest of the medium, some light will be scattered at each particle interface in the forward and backward directions. The rest of the light will be transmitted or absorbed. Much of the scattered light emerges from the original surface or the far surface of the object. If there is enough scattering, the light emerging from any surface will have nearly uniform hemispherical distribution. The distribution of light in directions other than specular (regular) is called <diffuse reflection>.

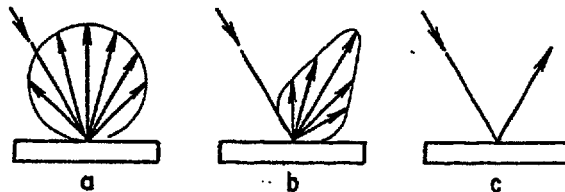


Fig.1. Three basic forms of reflection:
a) diffuse; b) mixed; c) specular (regular).

When light is not diffused or scattered by the surface of an object, the reflectance is usually called <specular>. Light transmitted by an object that is not scattered is called <regular>. Light reflected or transmitted by objects usually is neither completely specular (or regular) nor completely <diffuse> but is intermediate between these two extremes. That is, both specular and diffuse components are present. In Figure 1a, completely diffuse reflection is illustrated (the incident light is reflected in equal amounts at all possible angles, regardless of the direction of incidence). In Figure 1c, the incident light is reflected entirely at a single angle of reflection corresponding to the angle of incidence. In Figure 1b, reflected light is maximum at an angle of reflection corresponding to the angle of incidence, but some of the light is reflected throughout all possible angles. The situation illustrated in Figure 1b is most commonly encountered in nature. We distinguish between "glossy" and "matte" materials primarily on the basis of the tendency of reflected light toward the extremes shown in Figures 1a and 1c. If reflection is principally specular associated typically with objects having optically smooth surfaces, we call these objects "glossy". Transmission that is principally regular is associated with relatively homogeneous media which are typically called "transparent".

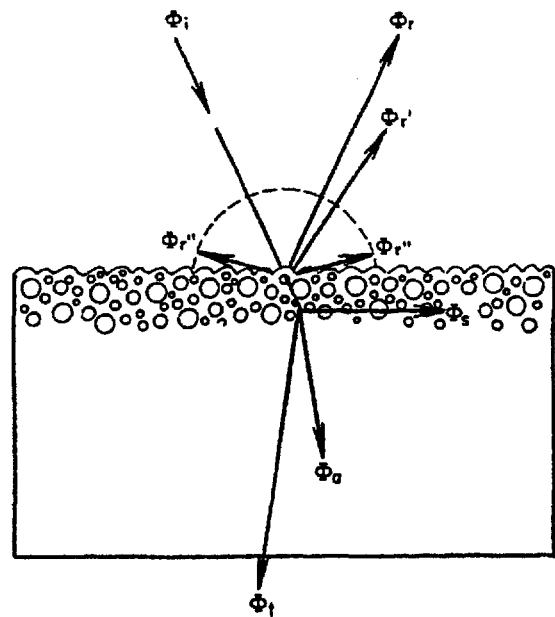


Fig.2. Phenomena occurring at an air/object interface.

With the interaction of light at or near the air/object interface, a number of complex phenomena take place. Figure 2 illustrates, generally, some of these phenomena. The incident flux (Φ_i) strikes the surface of the object. Some small portion of that incident light is reflected at an angle from the normal equal to the angle of incidence (Φ_r). Most of the light penetrates the medium. Some of it is absorbed (Φ_a); some of it is scattered (Φ_s); and some of it may find its way through the medium and be transmitted (Φ_t). Some of the incident flux may be reflected from irregularities that broaden the distribution of angles of reflected light ($\Phi_{r'}$). Some of the incident light, after interaction with particles within the medium, also finds its way back through the surface and exhibits a tendency to be distributed throughout all possible angles ($\Phi_{r''}$). The combination of directional quantities indicated by Φ_r and $\Phi_{r'}$ is generally related to the perception of what is called <specular gloss>.

It should be noted that, for most nonmetallic materials, light that is specularly reflected (Φ_r) has a spectral composition which does not change significantly from that which is incident. One observes the color of the light source. When incident light interacts with the particles deeper under the surface, some wavelengths are absorbed and others are reflected, changing the spectral composition of the light. These phenomena contribute to our perception of color.

The magnitude, size and frequency of surface irregularities determine the amount and angular distribution of $\Phi_{r'}$. It is the ratio between Φ_r and $\Phi_{r'}$, or, more explicitly, the rate of change

of light flux with observation angle, that largely determines what is perceived as <distinctness-of-image> gloss.

In some materials, there exists a layer of very small particles quite close to the surface. It is believed that this condition is responsible for the sensation called <haze>. This film, or layer, may be above or below the plane of the original surface and appears to be caused typically by a separation and migration of some component of the body medium or by a deposition on the surface by some atmospheric contaminant. Haze often has a bluish cast that is probably due to the same wavelength-dependent selective-scattering process that is responsible for the bluish appearance of the sky.

There are several other reflection-associated phenomena, such as interference effects that although they directly affect appearance, are not considered further in this report.

Polarization is another physical phenomenon which may result when light strikes a nonmetallic surface. This phenomenon is not directly identified by the human observer, but it may influence instrumental measurement. Although an in-depth analysis is not attempted here, it is useful to describe the most relevant aspects of polarization as related to gloss instrument performance.

The waves of unpolarized light vibrate freely in all directions perpendicular to the ray. Polarization occurs when this freedom has been limited in some manner. The incident and viewing beams of nearly all instruments contain elements that polarize the light to some degree. In glossmeters, the principal sources of polarization are the coiled filament lamp and mirrors (if used) when light strikes the mirror surface obliquely. Metallic first-surface mirrors produce a low level of elliptical polarization; however, most metallic mirrors are protected by a nonmetallic overcoat that may cause linear polarization. In some cases, the effect may be additive. Actually, the specimen is the major source of polarization, since it is an inherent part of the optical system and is, in effect, a nonmetallic mirror. The resulting polarization effect is maximum at about 60° incident and viewing angles. At angles less than or greater than 60°, the degree of polarization is significantly reduced. The range of index of refraction of materials such as coatings, plastics, papers, etc., that are candidates for gloss analysis is rather limited. Fortunately, the glass mirror-like standards used for calibration have indices of refraction similar to those of the specimens to be measured. Therefore, the effect of polarization in typical specular glossmeters is not normally significant.⁷

1.4 Capabilities of the Human Observer

When considering any attempt to measure physical quantities that may correlate with perceived gloss, it must be recognized immediately that, within the confines of current technology, the ability of any instrument to discriminate among the various attributes of gloss is extremely limited when compared to the capability of the human observer. Scales of gloss defined by geometric conditions that cannot be duplicated in instruments serve little purpose. For example, the attribute of distinctness-of-reflected-image is exceedingly difficult to measure photometrically without very high resolving power. Practical (that is, economically feasible) photometric reflectance instruments generally are limited to receptor field angles of about fifty times as large as the resolution capability of the visual mechanism.

Another limitation in measuring high-gloss materials is that no commercially available instrument can completely differentiate between a low reading resulting from poor image quality of the specimen and a low reading caused by surface curvature that has caused a divergence in the specularly reflected beam. The test sample must be very carefully selected or very rigidly clamped so that the surface to be measured is maintained in a flat, single plane. The human observer, however, can readily distinguish between these effects. Specimen nonflatness distorts but does not destroy the visual images reflected in its surface. In addition, the human observer has the freedom to manipulate the specimen during his judgment process. He can integrate the effect of these geometric variations during his appraisal. He is thus able to deal with this complex situation and make intelligent judgements relating to differences between the specimens.

Accordingly, one should not rule out the possibility of using a sensing human observer as part of any measurement system intended to provide complete quantitative specification of gloss. On the other hand, it must be remembered that the human observer requires two samples or a sample and a target standard in juxtaposition in order to make valid judgments and just as with any perception, there can be large differences between observers.

1.5 Status of Current Measurement Methods

To date, instrumental measurements designed to correlate with perceived gloss attributes have been limited to simple specular reflectance measurements, except in restricted situations.⁸

As previously explained, the complexity of the factors influencing gloss judgments has so far

Table 1-A, "Specular Gloss Methods of Industries"

This table lists specular-glossmeter geometries for specific applications to industrial materials, and the gloss range of the particular variety of materials to which a geometry has been applied.

Industrial Application	Axial Angles					
	85 Deg. Sheen	75 Deg. Specular	68 Deg. Specular	45 Deg. Specular	28 Deg. Specular	8 Deg. Specular
Paints	Matte paints		Medium-gloss paints		High-gloss paints	
Plastics			Medium-gloss plastics	Clear plastic films	High-gloss films & laminates	
Paper		Coated papers, inks			Cast-coated papers, waxed paper inks	
Ceramics			Medium- & low-gloss tiles	Abrasion of all tiles, porcelain		
Textile						
Wax and Finishing			Waxes, floor finishers			
Automotive					Auto-motive finishes	
Appliance					Finishes	Enamels
Metals						Metal Surfaces
General	Low- to medium-gloss materials	Low- to medium-gloss materials	Medium-gloss materials	Medium- to high-gloss materials	High-gloss materials	High-gloss materials

prevented the establishment of a general standardized set of geometrical conditions. Therefore, instrumental gloss scales have been empirically derived. Typically, a series of specimens representing gloss variations pertinent to a particular field of commerce has been assembled. These specimens were ranked by individuals involved with the specification and control of that type of material. An instrument was then developed, using incident and viewing angles close to those which the observer found to be best suited for judging the gloss differences represented by the specimens.

The incident and reflected beam field angles were empirically selected to produce measurements that correlated in rank with the visual judgments and that gave satisfactory numerical separation between representative specimens covering the applicable gloss range. This explains the selection of sixty degree axial angles and an intermediate size receptor window (field angle) for intermediate range coating products. Twenty

degree axial angles, with a very small receptor window, were selected for high-gloss automotive finishes. Eighty-five degree axial angles, with as large a receptor window as was physically practical, were chosen for low-gloss building interior finishes. The axial and field angles used in measurement of other products, such as coated and uncoated papers, have been similarly developed and are listed in Tables 1A and 1B. Current gloss test methods and standards are described in Section 3.

1.6 Areas of Future Concern

It is apparent, that much information on the subject of gloss and its measurement is, to say the least, incomplete. Terminology is inconsistent or lacking. Very few perceptual scaling experiments have been performed, and even these have been (for the most part) quite elementary. Of those instruments that have been developed for

Table 1-B, "Contrast Gloss Methods of Industries"

This table lists contrast-gloss geometries for specific applications to industrial materials, and the gloss range of the particular variety of materials to which the method has been applied.

Industrial Application	57.5 Deg. Polarization Contrast Gloss	45 or 60 Deg. Luster & Contrast Gloss	45 or 60 Deg 2-Parameter Contrast Gloss	30 Deg. Distinctness of Image
Paints		Low-gloss paints		Very-high-gloss finishes
Plastics				Very-high-gloss finishes
Paper	Low-gloss white paper	Ledger and writing papers		
Ceramics		Porcelains		Architectural tiles and porcelains
Textile		Fibers, yarns, fabrics		
Wax and Finishing				
Automotive				Body coatings & trim materials
Appliance				Enamels
Metals			High-gloss metal	Metal finishes
General	Low-gloss materials	Low-gloss materials	High-gloss materials	Medium-to-high-gloss materials

measurements relating to gloss perceptions, only the simplest (specular glossmeters) are in general use. Throughout the world, there appear to be few agencies equipped to provide measurement or calibration services. One might interpret all of this as an indication that geometric attributes of appearance are simply not important enough to warrant much expenditure of time and effort, or that the current elementary means of specification and measurement are satisfactory. Yet, appearance is becoming increasingly important in commercial specification and control applications in such diverse fields as coating and finishing, plastics production and fabrication, metals finishing, and paper and paper-board production, as well as in the performance evaluation of cathode-ray tubes and building glazing materials and in a myriad of other applications that affect our daily lives. In many of these applications, there are continuing changes and additions in production processes by which new and novel surface-appearance characteristics are created. These developments increasingly emphasize the gloss properties of materials and the observer's awareness of them.

There is a real and increasing need for identifying, specifying, evaluating, and controlling more types of gloss attributes than those covered by current procedures. The following is a suggested program of work that could eventually provide improved gloss-measurement procedures.

- Design and conduct a series of visual gloss scaling experiments with samples selected to exemplify a broad range of predominant gloss attributes. The experiments should involve ranking or pair-comparison judgments, and should include tests to determine the degree of dimensionality of gloss perceptions.
- Explore the alternatives for developing the test equipment and experiments that might lead to quantification of standardized observing conditions for gloss.
- Analyze the experimental data by means of multidimensional scaling techniques designed to identify the major axes (classes) of gloss and to provide psychometric scaling.
- Perform goniophotometric measurements of the specimens to provide the basis for correlation between the light-scattering properties of materials and the perceptual gloss scales.

- Develop instrument optical geometries and transformation equations in order to produce psychometric measurements.
- Study standard test methods for gloss with reference to the newly developed data. Prepare recommendations for revisions and additions to these test methods.
- Study the appearance attributes of metals. Adopt the test procedures for nonmetallic materials where applicable and devise additional scales where needed.

These tasks are fairly well identified. The experimental and analytical tools for multi-dimensional analyses seem to be adaptable to gloss scaling. The requirements for better means of specifications and communication appear to be fairly well established. All that remains is to carry out the work program within a reasonable time period.

2 GLOSS TERMINOLOGY

2.1 Rationale Behind the Philosophy

A review of the literature concerning gloss and an investigation of the state of the art of measurements relating to gloss attributes discloses that the terminology is not clear. In some areas, the terminology does not even exist. In the following, it is suggested that the terminology that is being used properly relates to perceptual quantities⁸ and is not properly used when applied to the property of a surface or to measurements of that property by means of current "glossmeters".

The need for a better glossary related to the subject of gloss becomes quite apparent as we attempt to design visual experiments in gloss scaling. Almost all previous experiments have attempted to establish a relationship between visual judgments of a single set of specimens and specific instrumental measurements. Gloss, on the other hand, is almost certainly multidimensional in nature and, if we are to establish gloss scales supported by instrumental measurement techniques, a series of geometries will probably be required.

Two aspects of the gloss-terminology situation became apparent to the authors. First, since gloss perceptions are multidimensional, terms are required to identify the various subclasses of gloss attributes. The classes identified in this section are based on the 1936 paper by Hunter⁶ and subsequent investigations carried out in the United States. Second, it is important to identify clearly the difference between physical,

perceptual (psychological), psychophysical, and psychometric terms and concepts. Correspondence between Hunter, Christie, and Billmeyer has resulted in an article that attempts to clarify these differences.⁹

The following recommendations on gloss terminology are structured primarily on the conclusions reached in that article.

2.2 General Terms Relating to Appearance

There are four classes of terms which can be applied to the phenomena associated with the appearance of surfaces and objects. The identification of the following general terms is in essential agreement with that proposed by Hunt in his recommendations for terminology related to colour attributes.¹⁰

1. **Physical** - Identifying the radiant energy and optical phenomena involved.
2. **Perceptual (Psychological)** - Denoting the perceptions in the mind of an observer. These are subjective sensations.
3. **Psychophysical** - Identifying, by means of some form of measurement, the human visual responses to physical stimuli. Psychophysics is the incorporation of psychological response aspects of the observer into a measuring system.
4. **Psychometric** - Identifying psychophysical scales in which equal scale intervals correlate with equal perceived differences. In this context, psychometrics is a subcategory of psychophysics in which visually equal scaling intervals are the central point of reference.

The authors recognize the possible confusion arising from the use of the term "psychometric" in this limited context. However, it is felt that it is the most appropriate term currently available for identifying scales with this particular characteristic.

2.3 Terms Relating to Gloss

Note that it is conceivable, indeed probable, that gloss terminology will have to include definitions of (and delimitations or boundaries for) surround conditions, e.g.: size of the light source, contrast between the light source and the extended background, and relative positions of the light source, the surface, and the observer.

2.3.1 Physical Terms

The physical phenomena associated with gloss are the directional distribution characteristics of light in (and adjacent to) the direction of specular reflection from a surface. They are

associated with the distinctions (and sometimes with the contrasts) between specular reflection, diffuse reflection, and mixed reflection.

1. **Specular (Regular) Reflection** - Reflection without diffusion in accordance with the laws of optical reflection, as in a mirror.
2. **Diffuse Reflection** - Diffusion by reflection in which, on the macroscopic scale, there is no specular reflection.
3. **Mixed Reflection** - Partly specular and partly diffuse reflection.
4. **Texture** - Macroscopic structure, pattern and topography of a surface.
5. **Directionality (Scattering Indicatrix, Azimuthally Nonisotropic)** - Difference in pattern of near-specular and partly diffuse scattered light, dependent upon the azimuth angles of the incident and viewing beams.

2.3.2 Perceptual (Psychological) Terms

Gloss - The mode of appearance by which highlights of objects are perceived as superimposed on a surface due to the directionally selective properties of that surface.

There are several classes of perceived attributes used in comparative studies of surfaces. They are:

1. **Specular Gloss** - Perceived surface brightness associated with the luminous specular (regular) reflection from a surface. Because the observer has difficulty judging brightness in an absolute sense, specular gloss is usually judged by comparison between the brightness of the surface of interest and that of a reference surface, present either deliberately or fortuitously. Specular gloss can thus be considered the result of an interspecimen judgment. A small-area source of light against a dark background provides a suitable condition of illumination for observation. The angles of incidence and view are not critical. Any angle within the range from 20° to over 60° is generally satisfactory.
2. **Contrast Gloss (Luster)** - Perceived relative brightness of brighter and less bright adjacent areas of a surface resulting from selective reflection in directions relatively far from those of specular reflection. Contrast gloss can thus be an intraspecimen judgment. It is normally evident in surfaces having low specular gloss. Suitable illuminating and viewing conditions are the same as those for specular gloss.
3. **Reflection Haze** - Perceived cloudiness, seen as scattered light reflected by a surface in directions near those of specular reflection. Reflection haze is observed in samples with

high specular gloss and, generally, high distinctness-of-image gloss. Haze appears immediately adjacent to the image of a very bright source seen against a dark background. Often the haze appears bluish in comparison to the image of the light source. A tungsten source, either frosted or bare filament, suspended in a darkened room provides satisfactory illumination. The observer's eye should focus on the specimen surface.

4. **Distinctness-of-Reflected-Image Gloss** - The sharpness with which images are perceived after reflection from a surface. The conditions of illumination require a well defined source with a black background. A black-velvet-backed fluorescent lamp with a coarse wire screen, as described by Hunter,¹¹ provides a suitable luminous source. The observer should focus on the image of the source.
5. **Sheen** - Perceived shininess at a large angle of incidence seen in otherwise matte specimens.

Other related attributes are:

6. **Perceived Texture** - Macroscopic structure, pattern or topography, as observed to be the property of a surface. Suitable illuminating and viewing conditions are generally the same as those for specular gloss. The observer will naturally focus on the specimen surface.
7. **Perceived Directionality** - The observed change of any of the above attributes of a surface with rotation of the surface in its own plane.

2.3.3 Psychophysical Terms

Following the philosophy that terminology which has been developed in relation to gloss attributes should be restricted to the perception, it is felt that no terminology currently exists that can be properly applied to the psychophysical attributes of gloss. The perceptual terminology is sometimes incorrectly applied to values derived from "glossmeters". When identified, psychophysical terms will describe measurements that are modelled to incorporate primarily the observer's response to spatial distribution of reflected light. It is of secondary importance that the model incorporates the observer's sensitivity to the chromatic characteristics of light (luminosity function). The model for the standard observer of gloss has not been developed.

2.3.4 Psychometric Terms

Gloss Scales - Any of a series of mathematical relationships that equate some function of the

goniophotometric curves with perceived differences between surfaces. Different scales should be developed as various gloss attributes can be isolated and modelled, i.e.: specular-gloss scale, distinctness-of-image-gloss scale, reflection-haze scale, etc.

3 CURRENT INSTRUMENTAL MEASUREMENT METHODS

3.1 Instrument Parameters

Gloss measurement invariably involves an abridged evaluation of the spatial distribution of the light reflected by an object, principally the surface-reflected light. Body-reflected (diffused) light can have an effect on glossmeter readings, and corrections for it can be made. However, such corrections are usually unnecessary because, in practice, gloss comparisons of surfaces of different color (lightness) are seldom made. In fact, the effect of diffuse reflection on gloss perceptions has not been quantified; therefore, the proper direction, as well as the magnitude, of such a correction is not currently known.

Most instruments are designed so that the overall response function is not significantly different from that which would be obtained if the incident light were CIE Source C (or D_{65}) and the detector had a response duplicating that of the luminous efficacy of the CIE Standard Observer. Surface-reflected light is seldom spectrally selective to a significant degree. Therefore, the response function can be somewhat different from that described and may have little

effect on gloss values. Some test methods allow the use of Source A in order to improve signal levels with lower input power to the source.

In any measure of specularly reflected light, the axial angle of view is equal to the angle of incidence. Glossmeter geometries are selected, in part, by this angle. A small angle from the perpendicular to the specimen is used for high-gloss evaluation. A large angle of incidence is used for evaluating microscopically rough surfaces to determine whether a surface that shows no gloss at near-perpendicular incidence will exhibit a marked increase in gloss (sheen) at a near-grazing angle of incidence. Intermediate angles of incidence and view are used for general gloss evaluation.

The angles of incidence and view, however, are only part of the necessary geometric specification for reproducible gloss evaluation. The source and receptor field angles are also even more important.

The terms, "field and aperture stops" and "field and aperture angles", are used in this document in the same manner in which they are traditionally used in the science of imaging optics. An aperture stop is used to control the size of the beam or the amount of light projected through the system. A field

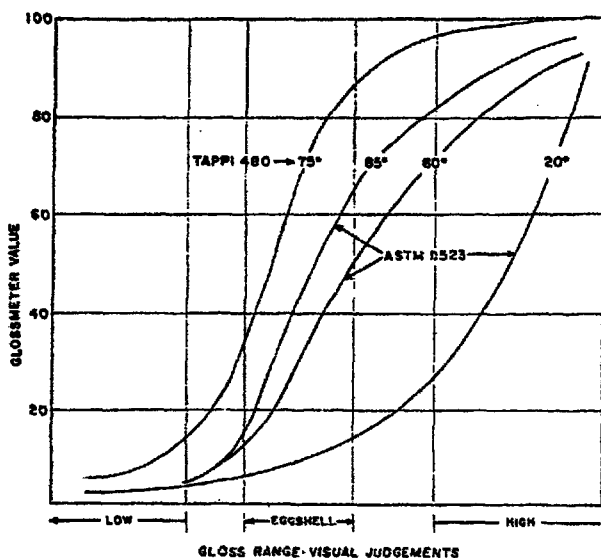


Fig.3. Qualitative relationship between specular gloss scales.

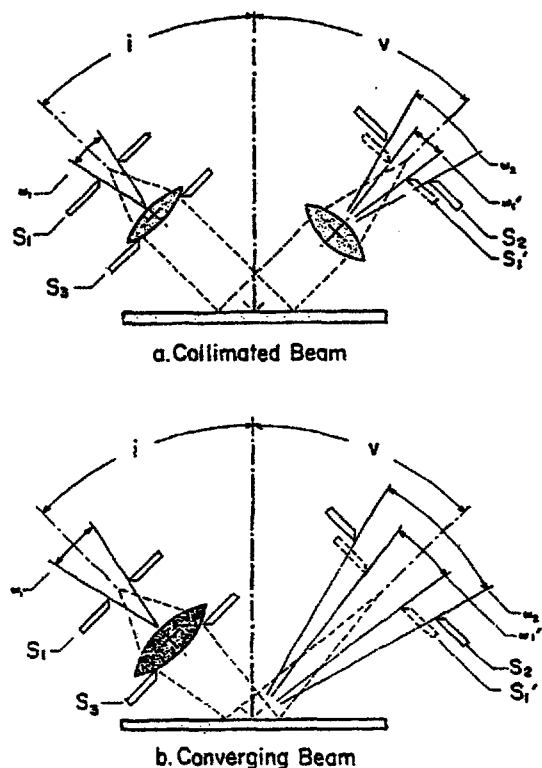


Fig.4. Specular glossmeters.

stop controls the angular field of view of the system, principally that of the objective lens. It is recognized that, in several important gloss test methods such as ASTM D523 and ISO 2813, this terminology has not been followed; however, the principal author of this document feels that this practice should be changed. The source and (more importantly) the receptor field angles are so critical in the measurement of the spatial distribution of light reflected from objects that they should be identified by the most explicit terms available. Problems involving reproducibility between instruments have, in fact, been caused by ignoring the importance of those dimensions. In the converging-beam optical system, the identification of field angles and aperture angles is difficult. However, the field angles, as identified in Figure 4b, perform the same function as those similarly identified in the collimated-beam system, in Figure 4a.

As shown in Table 2, these angles are measured in the plane and perpendicular to the plane of the incident and viewing beams. Accuracy and reproducibility are primarily dependent on the angles in the plane of the beams and less so for the angles perpendicular to the beams. For high-gloss differentiation, the receptor field angles are specified to be only slightly larger than the source field angles. For general gloss evaluation over the entire midrange, the same source field angles can be used with larger receptor angles. When evaluating sheen of low-gloss materials, even larger receptor field angles are appropriate.

Note that the various geometries were designed empirically to meet specific needs for evaluation of gloss of different materials, and they came into existence separately. They were not designed to provide a unified series of related gloss-measurement geometries. Figure 3 is constructed to convey some idea of relative values for four common specular glossmeter scales. The curve for the ASTM D523 60° scale was plotted by using (for the abscissa) average rank by four observers of twenty-four specimens.¹² The ordinate gives the 60° glossmeter values of those same specimens. The curves for the ASTM D523 20° and 85° scales and for TAPPI T480 75° scale were determined by subsequent measurements of a completely different series of specimens on the four types of glossmeter. It should be noted that each of these curves represents the average of a broad range of values and should be used for qualitative purposes only. Large variations can occur between gloss scale values with differing indices of refraction and surface characteristics of the specimens.

Specular glossmeters are designed and built with one of two kinds of optical systems designated as a collimated- or converging-beam; see Figure 4, in which ω_1 is the source field angle, ω_1' is the source field image angle, (ω_1' equals ω_1 in the collimated-beam design, but does not equal ω_1 in the converging-beam design), ω_2 is the receptor field angle, S_1 is the source field stop, S_1' is the source field stop image, S_2 is the receptor field stop, S_3 is the source aperture stop, i is the incident axial angle, and v is the viewing (receptor) axial angle. Note that, in either design, it is necessary to provide a uniformly illuminated source field stop and a detector which is uniformly responsive to all rays accepted by the receptor field stop.

Either design can be used and, if properly executed, will provide essentially the same reading within a reasonable tolerance and frequently within the precision with which the geometric requirements for either design are reproduced. The collimated-beam design is more sophisticated and more expensive, because it requires an additional lens. The converging-beam design eliminates the receptor objective lens and, in so doing, removes the possibility of vignetting or blocking by the lens holder of rays which should register. This design also has the advantage of providing (within a given overall size) a longer optical distance for source and receptor field stops. It thus allows higher precision in setting these angles. A disadvantage of the converging-beam design is that there is a larger diversion of reflected rays than with the collimated-beam design because of the convergence of rays in the incident beam. In addition, the receptor field stop views off-axis areas of the specimen at slightly different axial angles.

3.2 Abbreviated Descriptions of Published Test Methods

International

ISO 2813-1978, "Paints and Varnishes - Measurement of Specular Gloss of Nonmetallic Paint Films at 20°, 60° and 85°." Geometries are identical with those of ASTM D523 from which they were taken.

Australia

AS 1580 (1974), "Australian Standard Methods of Test for Paints, Varnishes, Lacquers and Related Materials, Method 602.2, Specular Gloss" (20°, 60° and 85°). Geometries are identical with those of ASTM D523 from which they were taken.

Table 2-A, "Specular Gloss Measurement Procedures"

This table lists the method, applications, field angles of source and receptor, primary standard and basic calibration, and glossmeter reading for a perfect white as well as for a perfect-mirror. The last two entries are useful for indicating relative characteristics of gloss methods, the perfect mirror value being an inverse indication for each geometry of the relative intensity of the reflected beam. The perfect-white values, multiplied by the cosine of the angle of view, provide an index of the relative sizes of the receptor field stops.

Gloss Type, Specular Angle, and Specification (see Table 4 for abbreviations)	Applications	Field Angles, Degrees (first angle given is in plane of measurement)		Primary Standard	Important Values	
		Source	Receptor		Perfect White (diffuse correction factor)	Perfect Mirror
Sheen 85° BS 3900, Part D5 ISO 2813 DIN 67530 METHOD #602.2 (AUST.) ASTM D523 FTM 141a/6103	Flat matte paints, camouflage coatings.	0.75 x 3.0 (max.)	4.0 x 6.0	G _s , black glass (n=1.567) = 100	0.03	161.5
Specular Gloss, 75° JIS P8142 JIS Z8741 TAPPI T480 ASTM D1223 (obsolete)	Papers including uncoated, coated, waxed and glassine.	<1 x 3	11.5 diam.	Black or clear glass (n=1.567) = 100	1.0	378
		2.8 x 5.7	11.4 diam.	G _s , black glass (n=1.54) = 100	1.0	385
Specular Gloss, 60° JIS Z8741	Paints and plastics high, medium, low, or intermediate in gloss.	<1 x 3	4.5 x 12.0	Black or clear glass (n=1.567) = 100	2.2	1000
BS 3900, Part D5 ISO 2813 DIN 67530 METHOD #602.2 (AUST.) ASTM D523 ASTM D2457 ASTM D1455 FTM 141a/6101 FTM 406/3051 NEHA LDI-2.13 JIS K7105		0.75 x 3.0 (max.)	4.4 x 11.7	G _s , perfect mirror = 1000, or black glass (n=1.567) = 100	2.1	1000
	Plastics.	0.75 x 0.75	4.4 x 11.7	G _s , perfect mirror = 1000, or black glass (n=1.567) = 100	---	1000
Specular Gloss, 45° JIS Z8741	High-gloss paints.	0.57 x 5.16	0.63 x 1.72	Black glass (n=1.523) = 100	0.14	1870
	Polyethylene and other plastic films; change of porcelain finishes after use.	<1 x 3	4.5 x 12	Black or clear glass (n=1.567) = 100	6.1	1675
ASTM D2457 ASTM C346 PEI-T2, T7, T18 JIS K7105		1.4 x 3.0	8.0 x 10.0	G _s , perfect mirror = 1000	5.4	1000
	Plastics	0.75 x 0.75	4.4 x 11.7	Black or clear glass (n=1.567) = 100	---	1675
Specular Gloss, 20° JIS Z8741	High-gloss plastic film, appliance, and automotive finishes.	<1 x 3	1.8 x 3.5	Black or clear glass (n=1.567) = 100	1.3	2032
BS 3900, Part D5 ISO 2813 DIN 67530 METHOD #602.2 (AUST.) ASTM D523 ASTM D2457 FTM 141a/6104 JIS K7105		0.75 x 3.0 (max.)	1.8 x 3.6	G _s , black glass (n=1.567) = 100	1.3	2032
	Plastics	0.75 x 0.75	1.8 x 3.6	G _s , black glass (n=1.567) = 100	---	2032
TAPPI T653 ASTM D1834	Waxed, lacquered, and cast-coated papers; high-gloss ink films.	1 to 2.5 diam.	5.0 diam.	G _s , black glass (n=1.54) = 100	3.8	2190
Specular Gloss, 0° JIS Z8741	Metal surfaces.	<1 x 3	Appropriate value.	G _s , black or clear glass (n=1.567) = 100	---	2050

Federal Republic of Germany

- DIN 67 530 (1982), "Reflektometer als Hilfsmittel zur Glanzbeurteilung an ebenen Anstrich- und Kunststoffoberflächen" ("Reflectometer as a Means for Gloss Assessment of Plane Surfaces of Paints and Plastics") (20°, 60°, 85°). Geometries are identical with those of ASTM D523 from which they were taken.

- MERKBLATT V/22/72, "Prüfung von Papier, Karton und Pappe, Messung des Glanzes" ("Method of Measurement for Gloss of Paper and Paperboard (45°, 1972). Contrast gloss at 45°. Measure 45°/45° gloss; then measure reflectance at 45°/0 and take ratio. This is a proposed, not final method.

Table 2-B, "Contrast Gloss Measurement Procedures"

This table gives applicable information for contrast gloss, similar to that contained in Table 2-A for specular gloss.

Gloss Type, Specular Angle, and Specification (see Table 4 for abbreviations)	Applications	Field Angles, Degrees (first angle given is in plane of measurement)		Primary Standard	Important Values	
		Source	Receptor		Perfect White (diffuse correction)	Perfect Mirror
Polarization contrast gloss, 57.5° $\frac{\rho_s - \rho_p}{\rho_s + \rho_p} \times 100$ JIS Z8741 (obsolete)	White paper, low gloss.				0.0	
0-degree contrast gloss, $(\rho_s/\rho_p) \times 100$ with 0-specular angle 45° or 60° y-near normal angle JIS Z8741 German MERKBLATT V/22/72	White or colored object. Paper and paperboard.	0.5 x 3.5	0.5 x 3.5			
2-Parameter gloss, $(\rho_s/\rho_p) \times 100$ JIS Z8741 (at 45° or 60°)	Smooth metal or nonmetal surfaces with high gloss.		<3 <15			
Specular gloss, 30° Distinctness-of-Image gloss, 30° ± 0.3 Narrow angle haze, 32° Wide angle haze, 35° ASTM E430	High-gloss image-reflecting characteristics of nondiffuse metal finishes, using abridged goniphotometer or goniphotometer.	0.44 x 7.0 0.44 x 7.0 0.44 x 7.0	0.38 x 4.0 0.14 x 4.0 0.4 x 4.0	6 _s , perfect mirror = 100	0.0	100.0
Contrast Luster $100 \left(\frac{R_s}{R_d + R_s} \right)$	Luster of textiles, low-gloss papers, and other materials.	2.8 x 5.7	8.0 x 10.0	Perfect diffuser = 0.0 Any black glass = 100	0.0	100.0
Image Gloss, 13 1/2°, ASTM C540	Porcelain-enamel surfaces.	Visual observations of Landolt rings.		Observer qualified by viewing images reflected by black glass plate.		

STANDARDS ORGANIZATIONS IDENTIFIED BY ABBREVIATIONS IN TABLE 2

ISO: International Organization for Standardization, Geneva, Switzerland.	TAPPI: Technical Association of the Pulp and Paper Industry, Dunwoody Park, Atlanta, GA, 30341, USA.
CPPA: Canadian Pulp and Paper Association.	PEI: Porcelain Enamel Institute, 1911 N. Ft. Myer Drive, Arlington, VA 22209, USA.
DIN: German Institute for Standardization, Berlin, Federal Republic of Germany.	NEMA: National Electrical Manufacturer's Association, 2101 L Street, N. W., Washington, D. C., 20037, USA.
JIS: Japanese Industrial Standards, Tokyo, Japan.	FTM: Federal Test Method, General Services Administration, Washington, D. C., USA.
ASTM: American Society for Testing and Materials 1916 Race Street, Philadelphia, PA, 19103, USA.	

France

MFT 30-064 (1974). Identical to ISO 2813-1978.

Japan

- JIS P8142-1965 (1971), "Testing Method for 75° Specular Gloss of Paper and Paperboard." In Japanese.

- JIS Z8741-1962 (1971), "Methods of Measurement for Glossiness" (0°, 20°, 45°, 60°, 75°). In Japanese.

United Kingdom

BS 3900: (45°). Part D5: 1980 (identical to ISO 2813-1978). "Measurement of Specular Gloss of Nonmetallic Paint Films at 20°, 60°, and 85°."

United States of America

- ANSI/ASTM C346-76, "45° Specular Gloss of Ceramic Materials." Same as PEI T-13. Developed originally for porcelain enamels but used now for other materials. Because porcelain enamels frequently have higher refractive indices than glass, a polished-black-glass standard of refractive index 1.540 is usually assigned a value of 55.9.

- ANSI/ASTM C540-78, "Image Gloss of Porcelain Enamel Surfaces" (13.5°). Visual instrument. Observer views reflections of groups of Landolt rings (open circles like the letter "C") of different size and orientation to determine smallest size for which orientation is discernable with certainty.

- ANSI/ASTM C584-81 (1976), "60° Specular Gloss of Glazed Ceramic Whitewares and Related Products." Method prescribes use of 60° angle of incidence but does not specify apertures. Presumably, they are the same as in D523.
- ANSI/ASTM D523-80, "Specular Gloss" (20°, 60°, 85°). Originally developed for paint materials and first published in 1939 with only 60° geometry. Now used for gloss evaluation of many types of material. The three geometries have been incorporated in Australian, German, and ISO methods for gloss of paint.
- ANSI/ASTM D1455-78, "60° Specular Gloss of Emulsion Floor Polish." Uses 60° geometry of D523.
- ASTM D1834-80, "20° Specular Gloss of Waxed Paper." Same as TAPPI T653.
- ASTM D2457-70 (1977), "Specular Gloss of Plastic Film" (20°, 45°, 60°). Uses 60° and 20° geometries of D523 and 45° geometry of C346 for intermediate-, high-, and low-gloss films, resp.
- ASTM D3134-74, "Recommended Practice for Selecting and Defining Color and Gloss Tolerances of Opaque Materials and for Evaluating Conformance." Describes procedures for establishing permissible tolerances for color and gloss differences from specified standards.
- ASTM D4039-81, "Reflection Haze of High Gloss Surfaces." Haze index is evaluated as the difference between 60° and 20° specular gloss readings.
- ASTM E430-78, "Measurement of Gloss of High-Gloss Surfaces by Goniophotometry" (30°). Developed originally for metals but applicable to other materials. Provides for measurement of specular reflectance at 0.3, 2.0 and 5.0 degrees from the 30° specular direction.
- ANSI/TAPPI T480 os-78, "Specular Gloss of Paper and Paperboard at 75°." Although its direct application is to coated paper, it may also be used for uncoated papers. Uses circular receptor aperture.
- TAPPI T653 os-76, "Specular Gloss of Waxed Paper" (20°). Uses 20° incidence and viewing but specifies large circular receptor aperture. Gloss scale is quite different from 20° geometry of ASTM D523 where receptor aperture is a small rectangle.

Methods Published by U. S. Organizations (Duplicating Those Already Listed)

- ASTM D1223-67, "Specular Gloss of Paper and Paperboard at 75°." Withdrawn in 1979 in favor of TAPPI T480 which will now be published in the "Annual Book of ASTM Standards."
- ASTM D1471-69, "Two-Parameter, 60° Specular Gloss." Method called for use of standard 60° aperture of D523 and smaller 20° aperture of D523. Method discontinued in 1977 because of

difficulty encountered in changing apertures and reproducibly repositioning them. Replaced by ASTM D4039-81.

- FTMS 141B (Paint) Method 6101, "Gloss, 60° Specular." Cancelled February 1, 1979; used ASTM D523 60° geometry.
- FTMS 141B Method 6103, "Gloss, 85° Specular (Sheen)." Cancelled February 1, 1979; used ASTM D523 85° geometry.
- FTMS 141B Method 6104, "Gloss, 20° Specular." Cancelled February 1, 1979; used ASTM D523 20° geometry.
- FTMS 406 (Plastics) Method 3051, "Gloss." Uses ASTM D523 60° geometry.
- NEMA LD3-3.13, "Surface Finish" (60°). Based on ASTM D523 60° geometry.
- PEI T-18, "45° Specular Gloss of Porcelain Surfaces." Same as ASTM C346.
- PEI T-20, "Image Gloss of Porcelain Surfaces." Same as ASTM C540.

3.3 Instrument Standards

In addition to a nonreflecting device for establishing the zero end of the scale, two types of gloss standards are required. First, a polished glass (ideally black) high-gloss standard is required to calibrate or standardize the upper end of the scale of any specular glossmeter. Black glass is used because the light rays refracted into the material are absorbed. Polished clear glass is generally unsatisfactory because of reflection from the second surface. However, there have been proposals to use a transparent quartz material in which the second surface is ground to an angle relative to the first surface. The angle chosen is one that will direct the image from the second surface to miss the receptor window of the instrument.¹³ Polished black glass standards are usually supplied with every glossmeter. They are also used as primary calibration standards in standardizing laboratories by measuring the refractive index of the glass. The fraction of incident light reflected in the specular direction for the particular geometry used is computed by the Fresnel equations for oblique reflectance.

The black-glass standard must be cleaned when used for calibration. A strong laboratory glassware detergent should be used. Fine optical polishing compounds can also be used to assure that no detergent-resistant films have accumulated on the surface. However, it must be noted that some degree of antireflection surface accumulates on a polished black glass, starting almost immediately after polishing.¹⁴ This action eventually ceases and the reflecting characteristics stabilize after some time period. It is therefore advantageous to use standards which

have been calibrated several months after polishing.

The second type of gloss standard, which should be supplied with every instrument, is a semigloss specimen whose intermediate gloss-scale reading will verify that the components of the optical system, particularly the source and receptor field stops, are properly adjusted. A minimum of one such standard at midscale should be used. Additional standards can be used to verify instrument accuracy in a range of values close to those for which accurate gloss measurement of specimens is desired. Intermediate standards of high permanence and durability have been made of glazed ceramic tile, porcelain-enamelled steel, and acid-etched black glass. Ground or sand-blasted glass, which has not been etched, has a surface-reflected light distribution which is not useful for checking geometric adjustments.

Intermediate-gloss standards should not be used for the routine calibration (standardization) of glossmeters, because the reflection character of such standards is subject to change with heavy usage. A polished-glass standard should always be used for this purpose. Intermediate-gloss standards would be useful for scale-range calibration only if the geometric distribution of surface-reflected light were the same as that reflected from the type of specimen being measured. Usually, this is not the case. In addition, it is quite difficult to clean the surface of an intermediate-gloss standard properly; and it is almost impossible, by visual detection, to determine whether or not it has been properly cleaned. It is recommended that intermediate-gloss standards be stored carefully and used only for instrument performance testing so that frequent cleaning is not necessary.

4. CALIBRATION AGENCIES

This section contains a compilation of agencies and calibration services throughout the world. They have been separated into listings of national and of commercial agencies. It must be noted that the instrument standards issued by the private or commercial agencies are not necessarily directly traceable to central-agency master calibrations.

ARGENTINA

National/Public Agencies

Instituto Nacional De Tecnologia Industrial (INTI)

Calibration Services offered: 20°, 45°, 60° and 75° specular gloss.

Instruments/Equipment used: Commercial, modified goniophotometer.

Test Methods: DIN 67530, ASTM D523, TAPPI T480, ISO 2813.

AUSTRALIA

CSIRO National Measurement Laboratory

Test Methods: Method No. 602.2.

CANADA

National/Public Agencies

National Research Council of Canada¹³

Calibration Services Offered: 60°, 20°.

Instruments/Equipment Used: Special instrument.

Test Methods: ISO 2813, ASTM D523.

FEDERAL REPUBLIC OF GERMANY

National/Public Agencies

Bundesanstalt für Materialprüfung (BAM)

Test Methods: ISO 2813, DIN 67530.

Physikalisch-Technische Bundesanstalt (PTB)

Test Methods: DIN 67530.

Private/Commercial Agencies

Byk-Mallinckrodt, Chemische Produkte GmbH

Instruments/Equipment Used: "Multi-Gloss."

Test Methods: DIN 67530, ASTM D523.

JAPAN

Private/Commercial Agencies

Murakami Color Research Laboratory

Instruments/Equipment Used: Digital Glossmeter GM-26D.

Test Methods: ASTM D523, ASTM C346 and TAPPI T480.

Suga Test Instruments Co., Ltd.

Instruments/Equipment Used:

4GV-4D Variable Gloss meter

- Incidence angle 20°-85°.

- Viewing angle 0°-85°.

- Angular setting occurrence 0.1°.

- Area measured 45 mm diameter.

Test Methods: ISO 2813, JIS K7105.

Nipon Denshoku Ind., Co., Ltd.

UNITED KINGDOM

National/Public Agencies

National Physical Laboratory

UNITED STATES

National/Public Agencies

National Bureau of Standards¹⁵

Calibration Services Offered: 20°, 60°, 85° specular gloss.

Instruments/Equipment Used: NBS-Gaertner Gonio- photometer.

Test Methods: ASTM D523.

Private/Commercial Agencies

Gardner-Neotec Instrument Division, Pacific Scientific Company

Calibration Services Offered, Test Methods:

20° Specular Gloss - ISO 2813, ANSI/ASTM D523, DIN 67530.

20° Specular Gloss - ASTM D1834, D2895, TAPPI T663, T682.

30° D/I Gloss - ASTM E430.

45° Specular Gloss - ASTM C436, PEI T-13.

60° Specular Gloss - ISO 2813, ANSI/ASTM D523, ASTM C584, D1455, D3052, DIN 67530.

75° Specular Gloss - ASTM D1223, TAPPI T480.

85° Specular Gloss - ISO 2813, ANSI/ASTM D523, DIN 67530.

Instrument/Equipment Used: Gardner Laboratory reference instruments.

Hunter Associates Laboratory, Inc.

Calibration Services Offered, Test Methods:

20° Specular Gloss - ISO 2813, ANSI/ASTM D523, DIN 67530.

20° Specular Gloss - ASTM D1834, TAPPI T663, T682.

30° D/I Gloss - ASTM E430.

45° Specular Gloss - ASTM C436, PEI T-13.

60° Specular Gloss - ISO 2813, ANSI/ASTM D523, ASTM C584, D1455, D3052, DIN 67530.

75° Specular Gloss - ASTM D1223, TAPPI T480.

85° Specular Gloss - ISO 2813, ANSI/ASTM D523, DIN 67530.

Note: Except for 75° Specular Gloss, these instrument standards are based on a physical standard with a specular gloss value determined at the NBS.

Instruments/Equipment Used: Reference instruments developed by Hunter Associates Laboratory, Inc.

5. REFERENCES

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CIE RESEARCH NOTE

MODELS OF HETEROCHROMATIC BRIGHTNESS MATCHING*

The conversion presented in this report is intended to supplement CIE $V(\lambda)$ based photometry and not replace it. Photometrists would be expected to decide when $V(\lambda)$ photometry, and when conversions to brightness related measures, are appropriate. In general current research indicates that luminance is appropriate when the observer's task is to resolve high spatial or temporal frequencies.

In 1978, TC-1.4 (Vision) produced a Technical Report (CIE Document No. 41) entitled "Light as a true visual quantity: principles of measurement". In that report the Committee expressed the view that:

"the measurement of light should be meaningfully related to vision as was originally intended by the CIE. We further believe that some practicable methods do exist for bringing the two (measurement of light and vision) into agreement. Four such techniques were described in Chapter 2. Admittedly, all complicate the measure of light beyond current practice. However, one of these, mathematical models in photometry, represents a potential solution for all the problems discussed above and its requirements for future instrumentation do not involve apparatus more complicated than the current physical photometers." (p.27)

Since that time, TC-1.4, and subsequently TC 1-03 under the CIE reorganization, has been seeking for a physiologically based, mathematical model of color vision capable of being able to transform luminance or tristimulus values to measurements more consistent with the perception of brightness.

In 1981, at a meeting of TC-1.4 (Vision) in Berlin, it was decided that the state-of-the-art of physiologically based, mathematical models of color vision would not permit a recommendation for photometric purposes in the near future. It was further reported that there is an urgent need to have light measurements better than that afforded by CIE luminance: 'better' meant a closer correspondence to brightness matching. If the CIE did not produce a recommendation along these lines, then industry would and their

recommendation is likely to be not as good as that possible from within the CIE. Therefore, it was decided to seek an interim solution to the luminance-brightness discrepancy problem by determining B/L ratios throughout chromaticity space from the data available in the literature. With these B/L ratios it would be possible to modify CIE luminance values to give a value more in line with the brightness matching of isolated chromatic lights.

In 1983, at the CIE Quadrennial Meeting in Amsterdam, Ware and Cowan circulated a report entitled "Specification of heterochromatic brightness matches: a conversion factor for calculating luminances of stimuli which are equal in brightness." This document contained an equation which, with a knowledge of the 1931 CIE chromaticity coordinates and CIE luminance, enable a new value to be calculated that was ordinarily related to luminances associated with the brightness matching of isolated lights. This equation was based on 3275 data points from 29 studies and the report fully documents the research that led to the final equation.

In 1984, at a meeting of TC 1-03 in Rochester, this report, including the Cowan and Ware equation, was accepted as an interim solution to the brightness-luminance discrepancy problem. It was further agreed to present the report to Division 1 as a Committee Report.

With this background, Division 1 recommends the Ware and Cowan conversion factors for further study.

The Ware and Cowan Conversion Factor

It is recommended that the conversion factors be used under the following conditions:

1. The stimuli should be viewed foveally, subtend a visual angle of greater than, or equal to, 30 minutes, but not greater than 4 degrees.
2. The stimuli have a luminance greater than, or equal to, 2 candela per square meter.
3. The stimuli to be compared should have similar surround conditions and appear as unrelated colors.
4. The ambient light is relatively neutral.

To compare two stimuli

1. Determine the X,Y,Z tristimulus values of each stimulus using the CIE 1931 color matching functions.

*This CIE Research Note was prepared by TC 1-03, chairman P. K. Kaiser, Dept. of Psychology, York University, 4700 Keele Str., Downsview Ont. M3J 1P3, Canada, and approved by Division 1: Vision and Colour for further study.