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METHODS OF DETERMINING GLOSS[1]

By Richard S. Hunter

ABSTRACT

Glossiness is evidenced by almost every object and is to be attributed to specular reflection. Specular reflection occurs at the surfaces of reflecting objects; and, because of the diversities of minute surface structure, many kinds of glossy appearance result. An attempt to classify these glossy appearances has led to the description of six different kinds of gloss: (1) specular gloss, identified by shininess; (2) sheen, identified by surface shininess at grazing angles; (3) contrast gloss, identified by contrasts between specularly reflecting areas of surfaces and other areas; (4) absence-of-bloom gloss, identified by the absence of reflection haze or smear adjacent to reflected high lights; (5) distinctness-of-reflected-image gloss, identified by the distinctness of images reflected in surfaces; and (6) absence-of-surface-texture gloss, identified by the lack of surface texture and surface blemishes.

In describing the appearances of objects, one commonly distinguishes between the effects due to two types of reflection; glossiness, on the one hand, may be correlated with specular, or surface reflectance; the degree of lightness or darkness may, on the other hand, be correlated with diffuse reflectance usually occuring within the pigmented and scattering media beneath these surfaces. Specular reflection is evidenced by light preponderantly reflected in the direction of mirror reflection, whereas diffuse reflection is evidenced by light scattered in all directions by the reflecting object. Unfortunately for the purposes of gloss and reflectance measurement, the effects of specular reflection and diffuse reflection cannot be completely separated. The gloss of a surface cannot, in the general case, be defined in any simple way that permits quantitative measurement.

Data which describe the directional distribution of light reflected by surfaces illuminated under specified conditions furnish the fundamental physical basis for describing gloss. However, such distribution data are cumbersome and involved and include the effects of both diffuse and specular reflection. It is because these goniophotometric (reflection distribution) data are unwieldy that, in the past, devices for measuring gloss have been developed by simple empirical means. By trial and error, methods have been found to measure the gloss of particular types of materials exhibiting particular types of gloss.

The article suggests that the designer of a prospective gloss meter should determine from goniophotometric data taken on representative samples what differences in apparent reflectance are most characteristic of the differences in glossiness observed visually. That is, gloss-meter design will have considerably less of the trial-and-error element when goniophotometric data are used to indicate the most pertinent reflectance measurements to make for various purposes.

Also included are descriptions of typical gloss instruments, descriptions of measurements they make, and a bibliography on gloss. Differences between the various types of gloss are analyzed in some detail.

[1] This paper was presented before the Thirty-Ninth Annual Meeting of the American Society for Testing Materials, Atlantic City, July 3, 1936. Preliminary papers on the same subject were presented before the Optical Society of America, in Washington, October 20, 1934, and in Philadelphia, October 25, 1935. (See reference [19] in bibliography.)

CONTENTS

I. INTRODUCTION

Gloss is possessed by most materials encountered in everyday life, and its occurrence is so common that persons seldom stop to give it particular notice. People are, nevertheless, responsive to the general appearance of objects and nearly everyone is able to form opinions as to the beauty, attractiveness, or striking appearance of things they see. Gloss is one of the major factors in appearance, and a number of methods for determining it have been developed. The purpose of these methods is usually to enable the producers and vendors of articles in commerce to rate them according to glossiness.

1. DEFINITIONS

It should be noted that the term "gloss" is used in this paper in a general sense to include all properties of surfaces responsible for effects such as "shininess", "sheen", "lustre", etc. Following Jones [24],[2] *gloss* and *glossiness* are here defined so that the actual physical properties of surfaces responsible for their glossy appearance may be distinguished from the appearance itself. That is, the *gloss* of a surface is considered to be a property of the surface; *glossiness*, the appearance that results because the surface possesses that property.

1. The *gloss* of a surface is its power to reflect light specularly. Since, unfortunately, specular reflectance is a quality which may not be separated by any objective measurement from diffuse reflectance in any but special cases, this definition of gloss does not, in general, describe a quantity that can be unambiguously measured until, in addition, the conditions of measurement are precisely stated. (See section V, p. 28.)

2. The *glossiness* of a surface is the appearance which results from its power to reflect light specularly. For any given surface, glossiness may vary with conditions of illumination and directions of view, but gloss is considered to be an inherent quality.

3. *Specular reflection* is that kind of reflection which causes surfaces to exhibit high lights and to appear somewhat like a mirror. This definition of specular reflection describes the process in terms of the appearance it produces and consequently does not explain the physical

[2] Numbers in brackets refer to the corresponding reference number in the bibliography at the end of this paper.

cause of gloss. Specular reflection is commonly contrasted with diffuse reflection, which is likewise defined in terms of the appearance it produces.

4. *Diffuse reflection* is that kind of reflection which causes a surface to possess lightness or darkness of some degree which may be represented on the scale of grays running from white to black. Specular reflection and diffuse reflection are constantly used in technical descriptions of the appearance of objects. Unfortunately there is no general way in which effects of these two processes may be accurately separated. It is impossible to measure specular reflectance and diffuse reflectance as separate entities in any but an approximate way. Consequently, the separate effects of the two processes cannot be rigorously specified; and the two processes are, for this reason, defined in the present paper in terms of the appearance each produces, even though it is customary to think of them as physically separate processes dependent upon the structure and composition of the object. Specular and diffuse reflection are discussed further in section IV, p. 26.

5. *Apparent luminous reflectance*, hereinafter termed *apparent reflectance*, is defined as the luminous reflectance a perfectly diffusing surface must have in order to yield the same brightness as the unknown surface under the same conditions of illuminating and viewing [35]. That is, any surface observed in any manner and illuminated by any combination of illuminants is compared to the theoretical, perfectly reflecting, perfectly diffusing surface observed and illuminated under exactly the same conditions. (See fig. 2 and section III.) In practice, of course, the theoretical, perfectly reflecting, perfectly diffusing surface is not obtainable, but material standards of known apparent reflectances may be obtained in several ways. For many cases, relative apparent reflectances are all that are needed and standards of known apparent reflectances are not required.

The plan of the present paper is to describe first the six different types of gloss in terms of the appearances they produce. Following this is a discussion of the directional distribution of light reflected by surfaces and the various measures thereof. With information thus at hand on the appearance characteristics resulting from the different types of gloss and on the basic method of reflectometry which is inseparable from the discussion of gloss, it becomes possible to develop relationships between these two phases of the subject.

II. SIX TYPES OF GLOSS

The necessity for a classification of gloss types arises when one attempts to grade materials for gloss, or to describe their differences in appearance. With two materials of the same general appearance, it is possible to say that one or the other has the higher gloss, or that the two appear about the same. For two materials of different appearance, however, it often cannot be stated which has the higher gloss. They may not show a common type of glossiness by which they may be graded.

From a study of the appearance by which the gloss of surfaces is commonly graded and from a study of the different existing gloss-measuring instruments and the properties they measure, a classification of gloss into six types has been devised. A classification was first made by the author in the fall of 1935 when, however, only five types were identified [18]. Table 1, which gives the classification, is

TABLE 1.—*Classification of the six types of gloss*

Type of gloss	Appearance characteristics produced	Most often used to describe appearance of—	Gloss range	References in bibliography
Specular gloss (formerly objective gloss).	Brilliance of specularly reflected light, shininess.	Paints, surfaces of moderate gloss, dark and chromatic objects.	Medium gloss	[3, 5, 14, 16, 17, 23, 31, 32, 39, 43, 44, 47, 52, 54.]
Sheen	Shininess at grazing angles.	Flat paints, papers, and materials of low gloss.	Low gloss	[37, 44.]
Contrast gloss (formerly subjective gloss).	Contrast between specularly reflecting areas and other areas.	Papers, mat and semimat finishes, white and light-colored materials.	Low gloss	[7, 8, 9, 11, 12, 15, 22, 24, 25, 26, 27, 28, 29, 33, 34, 44 45, 46, 48, 49.]
Absence-of-bloom gloss.	Absence of smear or excess semi-specular reflection adjacent to reflected high lights and images.	Surfaces in which reflected images and high lights may be seen.	High gloss	[21, 26.]
Distinctness-of-reflected-image gloss.	The distinctness and sharpness of reflected images.	Finishes, enamels, lacquers, and all smooth image-reflecting surfaces.	High gloss	[10, 18, 21, 43, 51. 53.]
Absence-of-surface-texture gloss.	Surface evenness, absence of texture, indicated by difficulty of recognizing presence of surface.	Glossy materials, finishes, and coatings.	Medium to high gloss	[17.

a modification of the previous table and lists: (a) the six types of gloss; (b) the appearance characteristics of each; (c) materials with which each type of gloss is most often identified; (d) the position in the general gloss range in which surfaces possessing each of the types of gloss are most often found; and (e) references to instruments which measure each type of gloss. Figure 1, reproduced from this article [18] serves to illustrate some of these types and shows photographs of gloss-comparator images reflected in four pairs of surfaces. The first two surfaces differ essentially in specular gloss, the second two in contrast gloss, the third two in bloom, and the fourth two in surface texture. Variations in distinctness-of-reflected-image gloss are also seen; for instance, the first two samples reflect images quite accurately, but the second two do not. Sheen, which was only recently added to the list, is not illustrated. Further details regarding these types of gloss, their significance and their measurement, are given in the later sections of this paper and in other papers [18, 19, 20].

This scheme of identifying gloss types is based upon observation and upon methods of classification and grading gloss that are already in existence. It is not intended to be the final and complete method for describing gloss and glossiness. There seem to be several types of glossiness that are not adequately explained by this analysis; for instance, some of the appearances that are associated with degree of polish are particularly hard to describe in the terms given in table 1. It is possible, however, that these effects may be treated as combinations of several of the types of gloss already identified. Many more data are needed on the correlation of differences in glossiness identified by observers and the results of instrumental measures of gloss. Viewed under different conditions, surfaces apparently present more than six different types of glossiness.

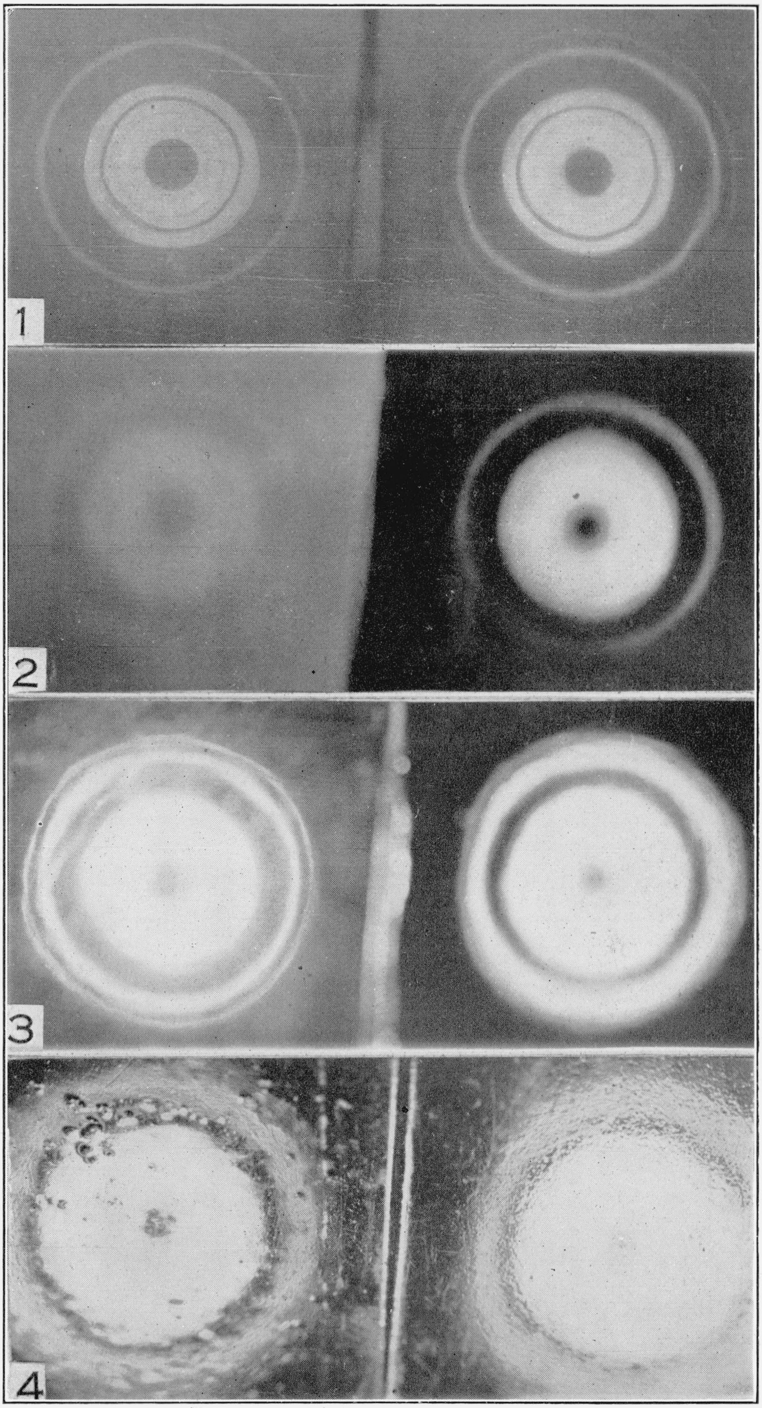

FIGURE 1.—*Images photographed with gloss comparator [18] showing types of gloss.*

1. The right image is brighter than the left image and depicts higher specular gloss. 2. The right image is from a black surface, the left image from a white surface. The black surface shows higher contrast gloss. 3. Although the left image is sharper, it shows reflection smear, or bloom. 4. Camera focussed on surfaces to record texture. Left: Pimpled; right: Orange peel.

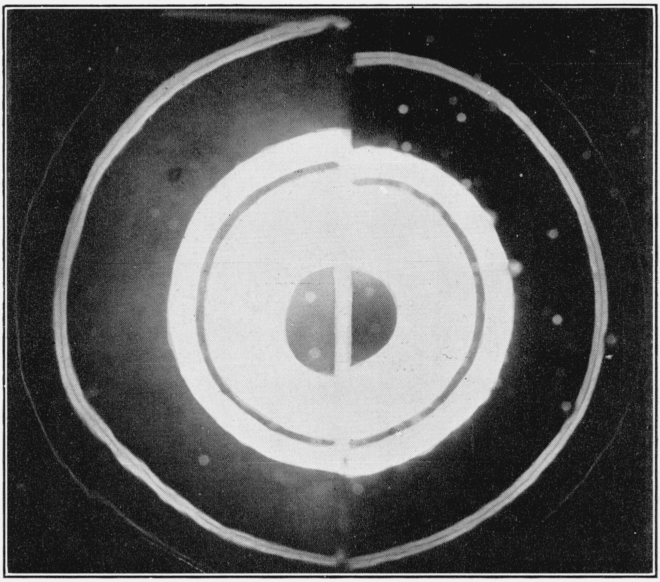

FIGURE 11.—*Gloss lamp target [21] reflected in pair of surfaces.*

The specimen on the left shows the reflection haze due to its bloom in the dark area of the image adjacent to the bright center circle. See text, page 35.

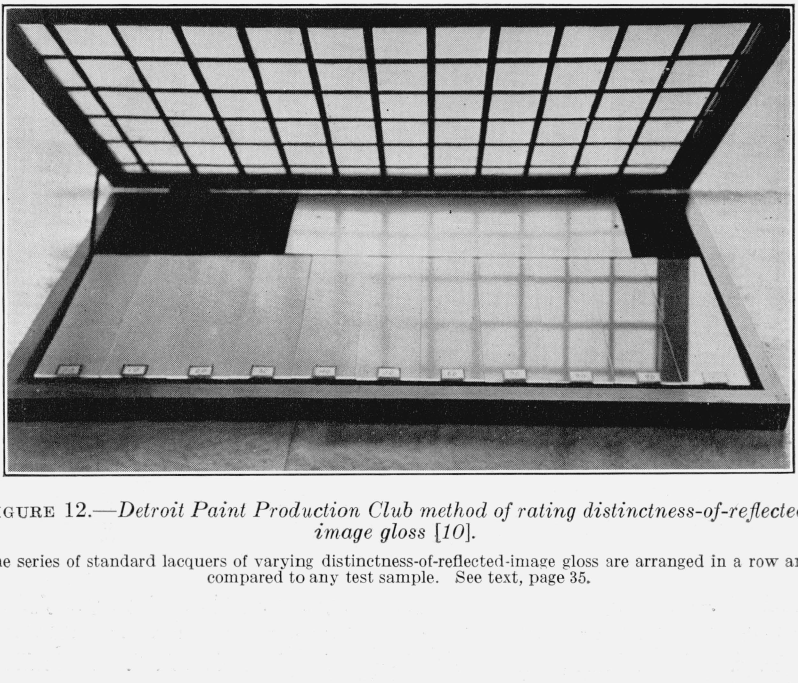

FIGURE 12.—*Detroit Paint Production Club method of rating distinctness-of-reflected-image gloss [10].*

The series of standard lacquers of varying distinctness-of-reflected-image gloss are arranged in a row and compared to any test sample. See text, page 35.

The need for simplicity in the treatment of the subject must be compromised with the need for an analysis of the problem complete enough to include within its scope methods of answering most of the questions that will arise. As an indication of the adequacy of table 1, it may be noted that it served to place, according to type of gloss measured, every one of the thirty-seven methods of measuring and analyzing gloss listed in the bibliography. On the other hand, some of the effects described in the papers dealing with the phenomenological and psychological phases of the subject were difficult to represent in terms of the six-gloss-type classification.

Smooth metal surfaces exhibiting metallic glossiness are distinguished by the fact that a major portion of the incident light is reflected specularly; whereas but 3 to 8 percent of the incident light is reflected specularly from nonmetallic surfaces at the nongrazing angles. Thus a major portion of the light incident upon a nonmetallic surface may be reflected diffusely whereas metallic surfaces are commonly characterized by a relative lack of diffuse reflectance. In spite of these differences, it is believed that, inasmuch as both metallic and nonmetallic surfaces exhibit specular reflectance, the above classification designed to describe nonmetallic surfaces may also be used to describe metallic surfaces. At present, however, no data are at hand to show the applicability of the six-type classification to descriptions of metallic appearance.

III. DIRECTIONAL DISTRIBUTION OF REFLECTED LIGHT

In this section the reflectance characteristics of surfaces responsible for glossy appearance are treated. Data describing the intensity distribution of incident and reflected light as a function of angle form the physical bases for descriptions of gloss. Such data are commonly presented as curves or numerical values giving, for specified angular distributions of illumination, values of apparent reflectance for different directions of reflection.

In figure 2, two experimentally obtained reflection-distribution curves are given together with a theoretical curve for comparison. In this diagram, light from a single direction is represented by *I* and is incident upon the reflecting surface, *O*, at 45°. *S* indicates the direction of reflection of this light for the case in which the reflecting surface is optically smooth and mirror-like. The curve *D* gives the apparent reflectance for the theoretical, perfectly reflecting, perfectly diffusing surface which possesses, by definition, an apparent reflectance of unity in all directions. It will be recalled that apparent reflectance is defined as the reflectance a perfectly diffusing surface would have to have in order to yield the same brightness as the unknown surface under the given conditions of illuminating and viewing. Compared to the perfectly diffusing surface, surfaces commonly reflect a disproportionately large amount of light in the general direction of mirror reflection because of gloss; consequently their apparent reflectance may rise to well above unity in that direction.

Curve *M* gives the apparent reflectance for a nearly mat sample of mimeograph paper; and *P* the apparent reflectance for a vitreous, porcelain-enamelled plate. As would be expected, the vitreous porcelain concentrates the reflected light about the direction of mirror reflection, rising to a measured apparent reflectance of 25.0 at 45°. In the case of the mimeograph paper, it can be seen that the apparent

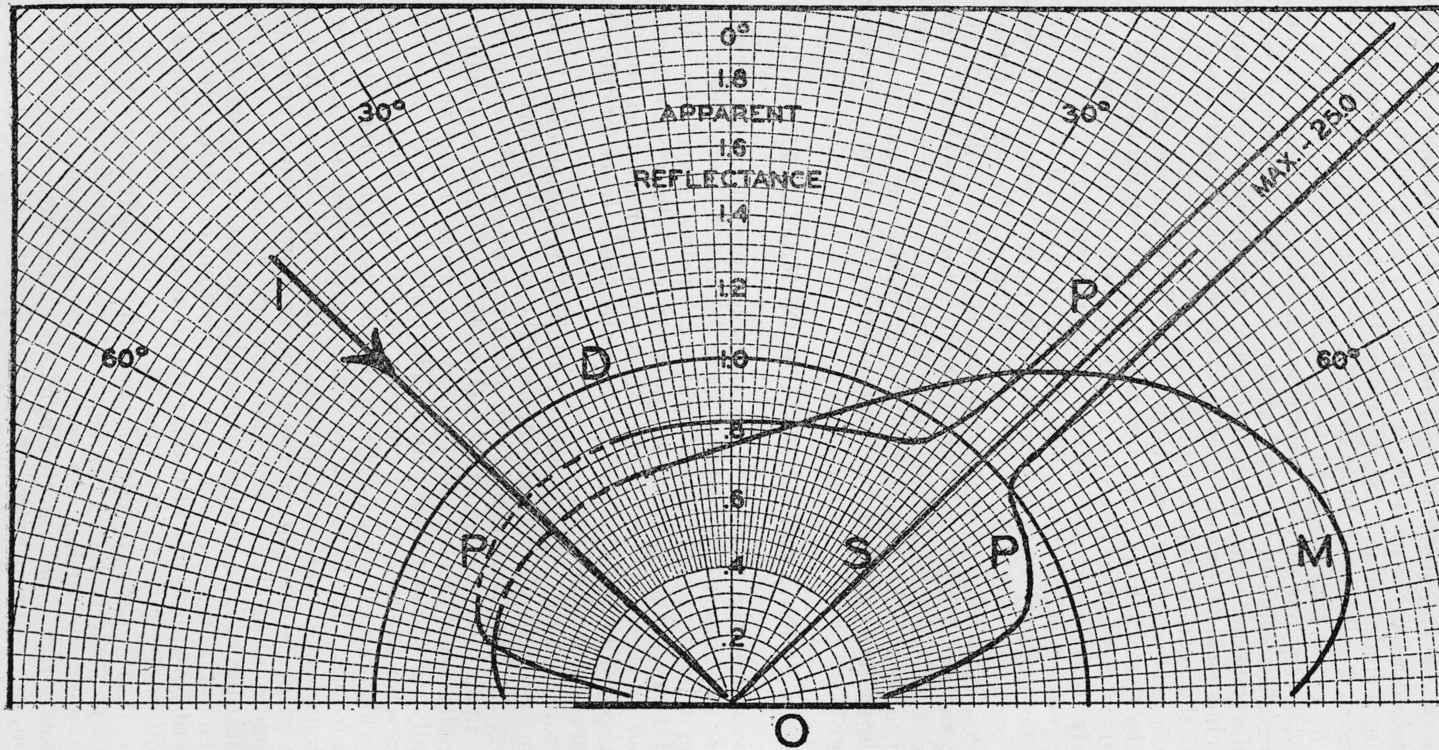

FIGURE 2.—*Reflection distribution curves for porcelain-enamelled plate, P, and sheet of mimeograph paper, M.*

Direction of incident illumination, *I*; direction of mirror reflection, *S*; reflecting surface, *O*; and reflection distribution for ideal, completely reflecting, perfectly-diffusing surface, *D*, also indicated.

reflectance is higher opposite the incident illumination but that there is no concentration of apparent reflectance in the direction of mirror reflection. In fact, it is interesting to note that the highest apparent reflectance appears in a direction further from the normal than mirror reflection. This type of curve is characteristic of many types of nearly mat surfaces.

Because it is known [3] that a freshly prepared magnesium oxide surface illuminated at 45° and viewed normally possesses an apparent reflectance of 1.00, secondary standards of reflectance obtained by comparisons with magnesium oxide are satisfactory standards of apparent reflectance for these conditions. If the apparent reflectance of a given surface is known for one direction of illumination and view together with its relative brightnesses for other directions of view, its apparent reflectances for these other directions may be derived because the brightness of the perfectly diffusing surface does not vary with direction of view.

The complete specification of a surface's ability to direct reflected light is so complex that it is virtually never determined. Light may be reflected by a surface in all directions; furthermore, with an infinite number of possible incident illuminations, each of which may result in a different distribution of light, the complete reflection-distribution specification for any surface is made up of a "quadruple infinity" of apparent reflectances. Instead of complete goniophotometric analyses, partial analyses such as shown by the curves presented in figure 2 are usually adopted. For example, only those values of apparent reflectance in the plane of the 45° incident beam and the normal to the surface are given in figure 2. In using single curves such as these, it must be realized that they do not present in any case the complete physical basis of glossiness and that there may often be reflectance effects of importance to the investigator not indicated by the data given. Thus, for example, figure 2, as it is given, does not show sheen because the illumination is not at grazing incidence.

Jones [24] was the first to emphasize the importance of goniophotometric measurements in gloss work. McNicholas [35] has treated the theoretical side of the subject and, in addition, published many valuable experimental data.

In discussing reflection distribution above, it was assumed that exact values of apparent reflectance for exact unidirectional illuminations and directions of view could be obtained. Actually, it is impossible to obtain curves for true unidirectional illumination and true unidirectional viewing because every source and every receptor used in a reflectance measuring instrument possesses finite size. It is doubtful whether there exists any goniophotometer possessing sufficiently small illuminating and viewing apertures to deal successfully with all gloss problems.

The eye is able to resolve images separated by one minute of visual arc. To equal the eye in distinguishing differences between surfaces of high gloss the goniophotometer should likewise be capable of revealing these effects in terms of brightness. Up to the present time it is believed that no goniophotometer has been produced which possesses this power of resolution. To build such an instrument it will be necessary to have the source and receptor of narrow aperture. For each determination, the light which reaches the reflecting surface from

[3] Preston, J. S., *The reflection factor of magnesium oxide,* Trans. Opt. Soc. London **31**, 15 (1929–30).

the source must follow a path in which all rays are parallel to within one minute of arc, and that reaching the receptor from the reflecting surface must satisfy the same conditions, so that, within this tolerance, light of one, and only one, direction of incidence and reflection is accepted for measurement. Only with such an instrument will it be possible to obtain sufficiently accurate reflection-distribution curves to differentiate all surfaces of high gloss.

Most of the goniophotometers now in use accept, for measurement in one setting, light reflected by the test surface at angles comprising several degrees. Therefore the distribution curves obtained with such instruments are less selective with respect to angle of reflection than are the ideal curves for unidirectional illumination and measurement. That is, each apparent-reflectance value obtained with an instrument of appreciable angular aperture represents the average of apparent reflectances for all the directions included in the measurement. Figure 3 is a diagram of the modification of McNicholas'

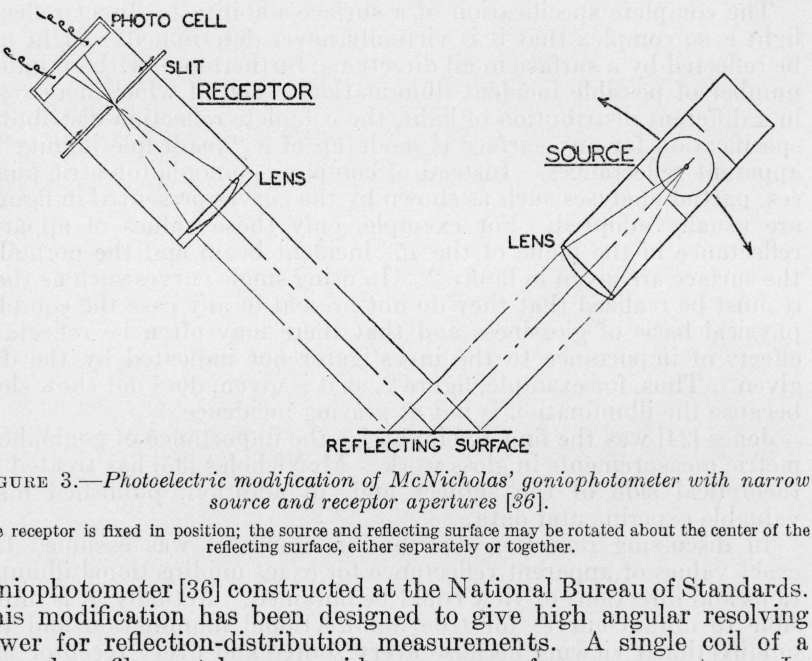

FIGURE 3.—*Photoelectric modification of McNicholas' goniophotometer with narrow source and receptor apertures [36].*

The receptor is fixed in position; the source and reflecting surface may be rotated about the center of the reflecting surface, either separately or together.

goniophotometer [36] constructed at the National Bureau of Standards. This modification has been designed to give high angular resolving power for reflection-distribution measurements. A single coil of a monoplane-filament lamp provides a source of narrow aperture. In front of the photocell receptor is an adjustable slit which can be made as narrow as desired, the only requirement being that sufficient light pass through it to give a current from the photocell that will register satisfactorily. This new apparatus was used to obtain the curves of figure 2. It will resolve about one-half of one degree. The source and sample may be rotated about the axis of the sample position, but the receptor position is fixed.

IV. SPECULAR AND DIFFUSE REFLECTION

In the previous sections gloss types have been classified according to appearance, and the fundamental reflectance method necessary for basic gloss specification has been described. The remainder of the paper will be devoted to relationships between these two phases of the subject. It was pointed out in the introduction that the concepts of specular and diffuse reflection are widely used in descriptions of the appearance of opaque objects. It has, in fact, been customary to say that specular reflection is responsible for gloss, although in table 1 above it may be seen that absence of diffuse reflection increases gloss of at least one type (contrast gloss).

In order to form a picture of the mechanism of reflection, one should consider the minute reflecting areas of individual particles as well as the larger visible areas of objects. Reflection occurs whenever light encounters a boundary between two media differing in refractive index. Specular reflection is ordinarily "first-surface" reflection taking place at the initial contact of the incident light with the reflecting object—as from enamelled tile. Diffuse reflection is, in most cases, principally a combination of reflection, refraction, and Rayleigh scattering taking place within the body of the reflecting object by the pigment particles and other particles having refractive indices differing from the refractive index of the surrounding medium. Only when the surface of an object is optically smooth is it possible to separate quantitatively the specular reflectance from the diffuse, the former in this instance being confined entirely to the direction of mirror reflection. The porcelain plate, represented by curve *P*, figure 2, is quite smooth. From its reflection-distribution curve, it may be seen that it would be possible to divide the observed reflectance satisfactorily into two components: one, diffuse reflectance, nearly constant in all directions; and the second, specular reflectance, which is the excess in the direction of mirror reflection.

For objects whose surfaces are not optically smooth—and the majority fall in this class—it is not possible to separate the observed reflectance into its components so easily. That is, it is not possible to decide, even approximately, what portion of the reflectance is diffuse and what portion is specular. The mimeograph paper, represented by curve *M*, figure 2, presents a characteristic reflection-distribution in which the usual transition from high reflectance in the approximate direction of mirror reflection to lower reflectance in other directions is wholly wanting—giving no indication of a separation into diffuse and specular components. Typical of materials which possess surfaces that are not optically smooth are semimat, painted finishes whereon protruding pigment particles or voids left after the evaporation of minute pools of volatile liquid break the smoothness of the surface; also sheets of paper in which there are voids between the individual fiber, pigment, and resin particles composing the sheet. Materials such as these frequently present a glossy appearance probably ascribable to a tendency for the individual surface units to follow the surface shape of the object.

Each specimen has its own reflection distribution, and only where the surface as a whole is optically smooth is it possible to separate the diffuse reflectance from the specular reflectance. For materials that differ as much in their power to direct reflected light as the white porcelain and white mimeograph paper of figure 2, the question of whether one or the other is lighter is obviously a question of how they are illuminated and viewed.

V. WHAT GLOSS METERS MEASURE

Most instruments designed to measure gloss actually determine some arbitrarily chosen type of apparent reflectance which has been found by experience to correlate closely with the particular type of gloss being studied. That is, most gloss meters have been designed empirically because few of their designers have had the opportunity to obtain goniophotometric data pertinent to the types of material whose gloss is to be measured.

It is advantageous for the designer of a gloss meter to determine from goniophotometric data on representative samples what particular apparent reflectance, or function of apparent reflectances, correlates best with glossiness, and then construct an instrument to measure this particular function. It is the object of research now being carried forward at the National Bureau of Standards to develop high-precision goniophotometric apparatus to study various gloss problems, to determine to what extent existing gloss-measuring apparatus is applicable to each problem, and to devise new apparatus if existing devices are found inadequate. Only Jones [24] is known to have made goniophotometric measurements on his materials before developing a gloss meter to measure them. The primary requirement for a gloss meter is that it give results which correlate satisfactorily with the gloss ratings on these same specimens assigned by visual inspection. In addition, the instrument should be reproducible from the description, so that the ratings obtained will not depend upon any particular instrument. Other desirable features are portability, inexpensiveness, ruggedness, and simplicity.

Information on three matters is needed in the description of a gloss-determining method: (1) direction and aperture of both incidence and view; (2) spectral composition of the light; and (3) polarization of the light. In describing any method of measuring gloss, the indication of (1) is most significant.

1. DIRECTION AND APERTURE OF INCIDENCE AND VIEW

For a complete description of a reflectance measurement, it is necessary to give the angles of incidence and reflection of all rays of light leaving the source and reaching the receptor by way of the test surface. That is, all those portions of the reflection distribution which enter the measurement must be given. Since every source of light and every receptor must possess finite size, illumination of the sample in any instrument comes not from a single point but from the integral parts of the source. Similarly, light leaving any one point of the surface of the sample may take any one of several directions and be incident upon various parts of the receptor. The elements that determine the possible combinations of angles of incidence and reflection by which light may travel from the source to the receptor are (1) the central directions of incidence and viewing, (2) the solid angular apertures of source and receptor, and (3) the area of the surface tested. Thus to describe completely the reflectance indication of a given gloss meter, it is practically necessary to have a drawing to scale of its complete optical system.

For an approximate angular specification of a gloss measurement, the factors of first importance are the angles which the axial rays of the incident and viewing beams make with the normal to the test surface. This information is available for practically all gloss meters. Thus, with Jones' gloss meter [24], figure 8, two beams reflected at 0° and minus 45° are compared, the surface being illuminated at 45°. Pfund's instrument [44], figure 5, always makes the angle of view equal to the angle of incidence of the illumination. The Ingersoll glarimeter [22], figure 9, measures the polarization of light reflected at minus 57.5°, with illumination incident at 57.5°.

In addition to the axial directions of illumination and view, data on the angular aperture of the light within the beams are important for the description of a gloss meter. This factor is of major importance in any measurement involving specular reflection, because, as can be seen from the reflection distribution curves above, the angular spread of specular reflectance varies markedly with type of glossy surface. To simplify the description of this factor so that all possible angles of incidence and view do not have to be stated, it is usually sufficient to give the maximum deviation, from the angle of mirror reflection, of any part of the beam accepted for measurement as specular reflection. To arrive at a figure which is fairly indicative of this maximum angular deviation from mirror reflection, one-half the sum of the angular apertures of source and receptor with regard to the reflecting surface may be taken for any instrument. In the case of the Ingersoll glarimeter a cone of light 13° in diameter is incident upon the glossy surface. (See fig. 9.) With the solid angular aperture of the viewing element, an artificial pupil, negligible when compared to the 13° of the source, the maximum angular deviation from the direction of mirror reflection of light accepted for measurement is 6.5°.

2. SPECTRAL COMPOSITION OF THE LIGHT

Spectral specifications include descriptions of the following three factors: (1) spectral distribution of energy from the source; (2) spectral transmissions of any filters in the system, and (3) spectral sensitivity of the viewing element. Almost without exception the instruments now being used to measure gloss employ an incandescent light source but do not use spectral filters [4] to alter the color of this source. Since the majority of instruments are visual, the usual viewing element is a human eye, and this possesses a spectral response similar to the adopted visibility function. However, several of the more recent gloss meters are photoelectric, and some of these use cells whose spectral responses differ quite markedly from that of the average human eye. Where such cells are used, and particularly where these possess appreciable infrared or ultraviolet sensitivity, either the response of the cells should be corrected to approximate visual sensitivity, or the results should not be used as if they were equivalent to visually obtained values.

3. POLARIZATION OF THE LIGHT

Because light specularly reflected at any angle other than normal is, in general, partially polarized, instruments which measure specularly reflected light must be described so that the effect of the optical components upon the state of polarization of the light will be given.

[4] In some few cases, instruments which measure contrast gloss make provision for the use of a selective spectral filter when highly chromatic surfaces are to be measured. It is advisable to do this in order to eliminate chromaticity differences from the photometric field.

Light specularly reflected from glass at about 57° is completely plane-polarized. For many materials having surfaces less smooth than polished glass, the light specularly reflected at this angle is to a major degree also plane-polarized. A method frequently used to measure contrast gloss [15, 22, 25, 46] employs a doubly refracting prism to separate (1) this plane-polarized specular component of reflectance together with half the diffuse reflectance from (2) the other half of the diffuse reflectance, which is plane-polarized at right angles to the specular component. By means of a polarizing prism the intensities of the two separate beams may be compared and a value of contrast gloss obtained (see Ingersoll glarimeter, fig. 9). Instruments which employ this type of contrast measurement give results that usually differ from the contrast-gloss measurements made by other instruments.

VI. SPECULAR GLOSS [5]

In the preceding sections gloss and gloss measurements have been treated in a general way. The six types of gloss will now be considered separately and the devices by which each may be measured described.

Apparent reflectance in the direction of mirror reflection is indicative of specular gloss as shown diagrammatically by figure 4. The shininess of a surface, the brilliance of its reflected high lights, and its specular reflectance are the appearances corresponding to specular glossiness. In this paper the term sheen has been applied to specular gloss at near-grazing angles.

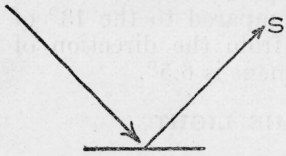

FIGURE 4.—*Specular gloss indicated by apparent reflectance in direction of mirror reflection, S.*

Specular gloss is probably the simplest type of gloss to determine, since its measurement involves finding only the apparent reflectance in the direction of mirror reflection through an instrument aperture which is adapted to the types of surfaces studied. To determine values of specular gloss, permanent standards of apparent reflectance are used to calibrate the photometric device used to make the measurements. Pfund's glossimeter [44], figure 5, uses black glass standards of reflectance and a pyrometer lamp for photometer. This instrument may be adjusted to measure specular gloss at any angle of reflection desired.

Specular gloss measurements are most commonly applied to materials of medium glossiness such as house paints, linoleums, printing ink, etc. On surfaces of low gloss the apparent reflectance in the direction of mirror reflection is often but little larger than the apparent reflectance in other directions. (See curve *M*, fig. 2.) For such surfaces, glossiness is usually better indicated by measures of contrast gloss than by measures of specular gloss. For surfaces of high gloss where the apparent reflectance in the direction of mirror reflection is of the same order of magnitude as the apparent reflectance from perfectly polished surfaces of the same material, one cannot distinguish differences in specular gloss as readily as differences in the distinctness of images

[5] Formerly termed objective gloss [18, 44].

reflected in such surfaces, or differences in bloom, or surface texture. In other words, all surfaces of high specular gloss appear shiny, but small differences in shininess do not attract attention as do the more apparent differences in other gloss qualities.

In designing any device to measure specular gloss it is desirable, on the one hand, to have the angular apertures relatively small so that the instrument receives for measurement only light that is reflected in nearly the exact direction of mirror reflection. On the other hand, surfaces that are warped or wavy furnish a difficult problem when measured by instruments of small aperture, because such surfaces slightly misdirect some of the specularly reflected light so that it misses the narrow aperture and has no part in the resulting measurement. An observer grading surfaces for shininess may see reflected

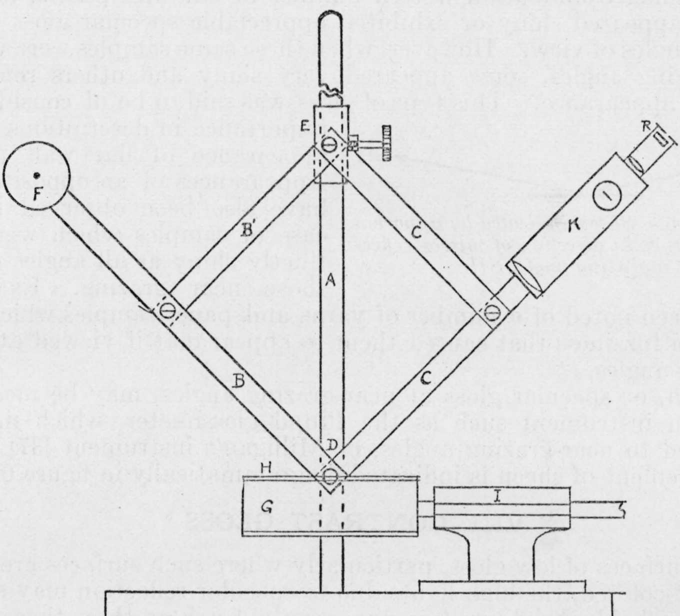

FIGURE 5.—*Pfund's glossimeter—An adjustable, visual, specular-gloss meter* [*44*].

The sample is bent in the form of a cylinder over *H*.

Light from the source, *F*, is specularly reflected by the test surface and measured by means of a pyrometer lamp, *K*. It is possible to vary the angle at which measurements of specular reflection are made.

high lights displaced because of warpage or waviness, but he discounts these warpage effects in visual grading; consequently an instrument to make the same gradings must discount the effects also. This requires instrument apertures larger than otherwise needed. In designing a specular-gloss meter to measure house paints and other products in the range of medium glossiness, the author [16] found that a source aperture 8.5° in diameter, for an angle of reflection 45°, is satisfactory; the receptor aperture, an artificial pupil, is in this case relatively small.

As explained above, specular gloss measurements are measurements of apparent reflectance employing the direction of mirror reflection and as small an aperture surrounding this direction as the curvature and waviness of surfaces will permit. This makes specular gloss measurements nearly equivalent to measurements of the so-called specular reflectance in that they are less affected by the so-called diffuse reflectance than are other measurements of gloss. For this reason measures of specular gloss are used to compare the gloss characteristics of surfaces of different hues and different lightnesses. In the paint industry, for instance, it is customary to say that white, black, and chromatic paints which have the same vehicular composition and thus have about the same specular reflectance characteristics, have the same gloss. A specular-gloss instrument is well suited to measure them.

VII. SHEEN

The author was only recently introduced to sheen as a type of gloss. Undergoing examination were a number of flat wall paints, none of which appeared shiny or exhibited appreciable specular gloss at the usual angles of view. However, when these same samples were viewed at grazing angles, some appeared very shiny and others remained mat in appearance. This type of gloss was said to be of considerable importance in descriptions of the appearance of flat wall paints. Appearances of an opposite type have also been observed in the case of samples which were distinctly shiny at all angles except those near grazing. Examples have been noted of a number of yarns and paper samples which possessed a fuzziness that caused them to appear mat if viewed at near-grazing angles.

FIGURE 6.—*Sheen indicated by apparent reflectance in direction of mirror reflection at a grazing angle, SH.*

Sheen, or specular gloss at near-grazing angles, may be measured with an instrument such as the Pfund glossimeter, which may be adjusted to near-grazing angles, or Milligan's instrument [37]. The measurement of sheen is indicated diagrammatically in figure 6.

VIII. CONTRAST GLOSS [6]

On surfaces of low gloss, particularly where such surfaces are white or light-colored, the high lights due to specular reflection may appear distinguishably brighter, but not greatly brighter than those areas which do not reflect high lights to the observer. When one views a surface of low glossiness, he seems to appreciate the contrasts between areas reflecting to him specularly and adjacent areas reflecting diffusely. Such a contrast measurement is indicated diagrammatically in figure 7. Contrast-gloss measurements are employed for materials such as paper, flat wall paint, flat lacquer, yarn, etc.

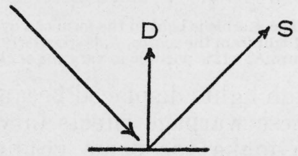

FIGURE 7.—*Contrast gloss indicated by contrast between apparent reflectance in direction of mirror reflection and apparent reflectance in another direction.*

(Possible functions are $1-D/S$ and S/D)

Since the gloss of these materials is low, the excess light due to specular reflectance is widely distributed in the general direction of mirror reflection in a manner characteristic of such surfaces (see curve *M*, fig. 2). For this reason the apertures of instruments used to measure this type of gloss may be

[6] Formerly termed "subjective gloss" [18, 44].

made large if desired. Two contrast-gloss meters are illustrated in figures 8 and 9. In Jones' instrument, figure 8, it may be seen that the apparent reflectance at 45° is photometrically compared with the apparent reflectance at normal viewing.

In the Ingersoll glarimeter, figure 9, the large source-aperture (indicated by the heavy lines, 1 by 1 inch opening, 5¼ inches from the center of the sample) is equivalent to a circular opening approximately 13° in diameter. Since this instrument is generally employed

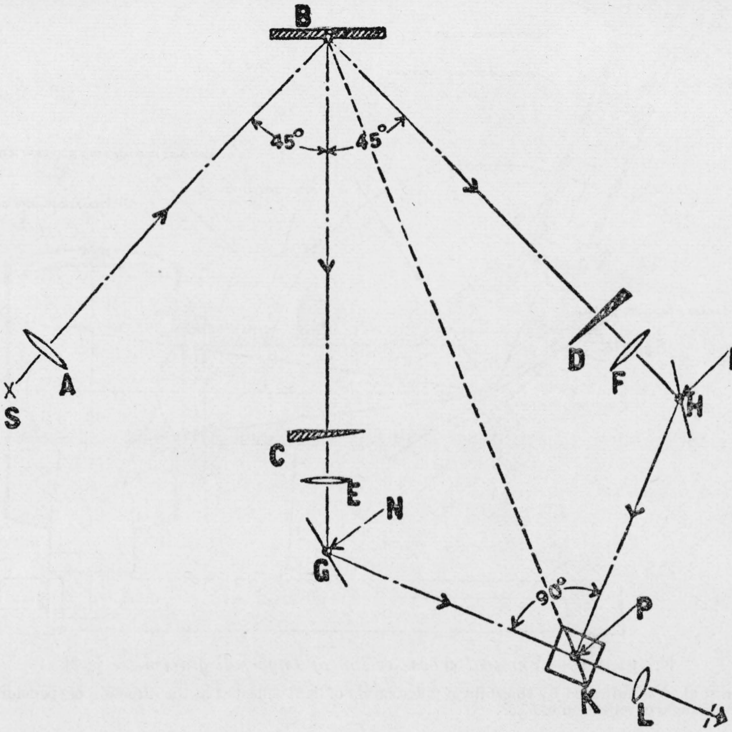

FIGURE 8.—*Diagram of Jones' contrast-gloss meter* [*24*].

Light from the source, *S*, is incident upon the sample, *B*, at 45°. The apparent reflectance at —45° (diffuse plus specular) is brought into juxtaposition with the apparent reflectance at 0° (diffuse) by means of mirrors, *G* and *H* and the Lummer-Brodhun cube, *K*. The observer can adjust the resulting beams to equal brightness by means of wedges *C* and *D*. The relative brightness of the two reflected beams is given by the inverse ratio of the transmissions of the wedges necessary to bring them to balance in the eyepiece.

throughout the paper industry, it probably enjoys wider use than any other gloss meter. The angle of reflection is 57.5°, the angle of polarization for paper. A doubly refracting Wollaston prism is employed to divide the reflected beam into two beams polarized at right angles for comparison.

IX. ABSENCE-OF-BLOOM GLOSS

By bloom is meant the appearance of haze or smear upon a glossy surface adjacent to a strong specularly reflected high light. Bloom appears most strikingly on dark surfaces which give by reflection relatively bright images; thus, on a highly polished automobile finish, the smear from a dirty rag or a little oil is plainly visible, particularly when the surface is viewed near an adjacent high light. But little scientific work has been done on this type of gloss, although it seems to have an important influence on appearance.

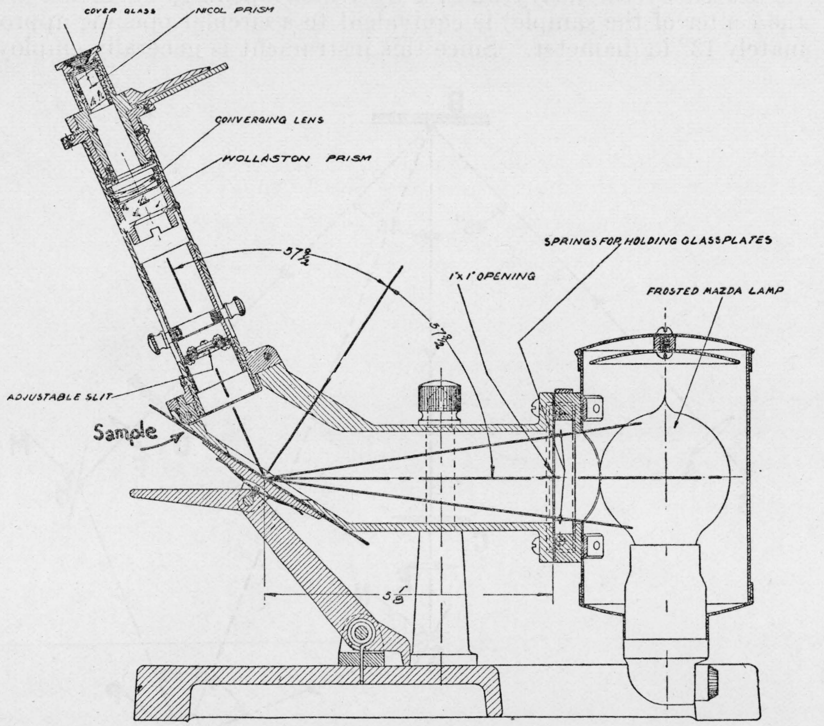

FIGURE 9.—*Vertical cross-section of Ingersoll glarimeter [22].*

Contrast gloss is indicated by the state of polarization of light reflected in the direction of specular reflection for an angle of reflection of 57.5°.

This completes the list of types of gloss which are at present subject to photometric determination. Except for a little work that has been done on metallic surfaces [26], little is known about the quantitative aspect of bloom, which is indicated visually by an excess of apparent reflectance adjacent to the mirror reflection. Whether, for its measurement, it will be desirable to take the difference between apparent reflectance in the direction adjacent to mirror reflection and apparent reflectance in a direction well removed from mirror reflection, or to take some other function of these apparent reflectances, is not yet decided. Different possible magnitudes for indicating bloom are suggested by the diagram in figure 10. In any case, care must be exercised to insure that none of the strongly reflected high light is admitted as bloom.

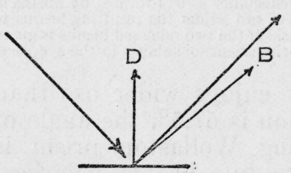

FIGURE 10.—*Bloom indicated by excess of apparent reflectance adjacent to mirror reflection.*

(Possible functions are $B-D$, $1-D/B$, and B/D.)

In figure 11,[7] from [21], is shown a comparison of the power of two surfaces to reflect images of the target used in the gloss lamp. The specimen on the left clearly shows bloom in the dark areas of the image.

X. DISTINCTNESS-OF-REFLECTED-IMAGE GLOSS

Surfaces which give images by reflection are, in general, surfaces of high gloss. Because these images are often the most pronounced feature of the appearance of a surface of high gloss, they are widely used as a criterion in gloss investigations. No photometric method of measuring distinctness-of-reflected-image gloss has as yet been developed, but this type can probably be associated in magnitude with the steepness of the reflection-distribution curve in the region of specular reflection

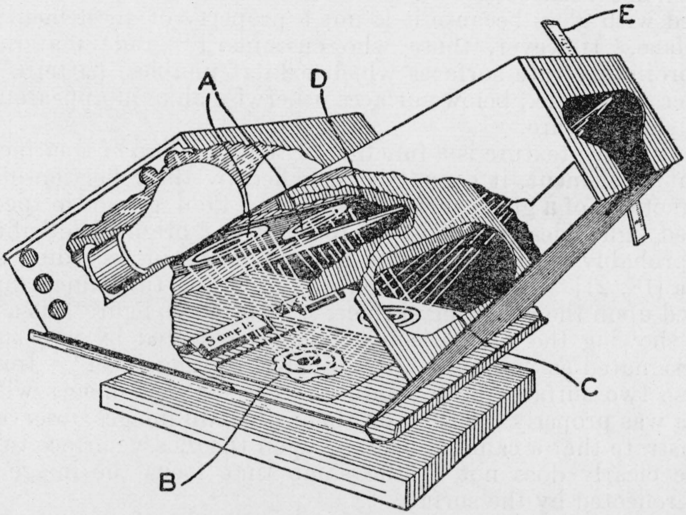

FIGURE 13.—*Hunter gloss comparator for determining distinctness-of-reflected-image gloss [18].*

A pair of target patterns, *A* (reflected images of which may be seen in figs. 1 and 11), are illuminated from behind. An observer views the images of this pair of targets, one of which is reflected by the test surface at *B*, the other by the glass mirror at *C*. The image of the target reflected by the glass mirror is diffused by means of a ground-glass plate, *D*. Motion of this plate toward or away from the target varies the amount of diffusion of the target image, and the position of the glass plate for which the distortion produced by the test surface and that produced by the movable plate appear equal may be determined by an observer and noted on the gloss scale, *E*.

(see curve *P*, fig. 2). So far the methods which have been developed to measure it depend on empirical comparisons.

Probably the method most widely used to reveal gloss differences consists in the comparison of the reflected images which two surfaces give of a window sash. This procedure is usually one of grading the specimens for distinctness-of-reflected-image gloss.

Figure 12[7] illustrates one attempt to establish a distinctness-of-reflected-image gloss scale on a more permanent and reproducible basis than is furnished by the window sash combined with day-to-day comparisons of samples and standard. In 1932 the Detroit Paint Production Club [10] developed a series of standard lacquers of varying degrees of distinctness-of-reflected-image gloss. These lacquers were

[7] Opposite page 23.

arranged on panels and under a lattice frame as illustrated in figure 12. The images reflected by the test sample were compared with those reflected by the members of the series of standards. Lack of permanence of the lacquer standards apparently proved to be the chief obstacle to the success of the scheme.

The Gloss Comparator developed by the author [18], figure 13, is an instrument designed to measure distinctness-of-reflected-image gloss on a continuous scale.

XI. ABSENCE-OF-SURFACE-TEXTURE GLOSS

The term "surface texture" is used to indicate all departures from surface smoothness sufficient in magnitude to be visible to the unaided eye. It has been suggested that surface texture should not be associated with gloss because it is not a property of an elemental area of surface. However, those who customarily grade materials for gloss ordinarily rate surfaces which exhibit pimples, patterns, waviness, scratches, etc., below surfaces otherwise alike in appearance but free of such texture.

Since surface texture is a function of the variation of a surface from element to element, it cannot be specified by the reflection-distribution functions of a given surface test area. Photographs in specularly reflected light (designated in microscopy as "bright-field" illumination) probably furnish the best known means of recording surface texture [18, 21]. In making such a photograph the camera must be focussed upon the reflecting surface. Thus, no. 4, figure 1, is a photograph showing the comparison of images reflected by two surfaces, one designated as "pimpled", the other as "orange peel." Inasmuch as these two surfaces both produced very distinct images when the camera was properly focussed on them, the two images observed here demonstrate that a camera focussed upon the glossy surface to record texture clearly does not at the same time focus the image of the object reflected by the surface.

Many phenomena interesting psychologically are associated with surface texture. There are rivalries for visual fixation between the texture of the surface and the images reflected in the surface. Stereoscopic effects may also be present because of the fact that an observer's two eyes receive images from a single source reflected in two different areas of the image-reflecting surface, with the result that the appearance to one eye is often quite different from the appearance of the same object to the other eye.

In [18] it was suggested that the characteristic of appearance which is commonly known as "depth of finish" might be explained as being due to lack of surface texture. Apparently an object possesses "depth of finish" when the surface of this object presents no texture upon which the one who views the surface may fixate. When the surface of an object is thus nearly invisible, the observer tends to see details of grain or mottling as appearing to be at an unlocated depth within the object.

XII. SUMMARY

The problems of gloss determination differ from many other problems of measurement in that the principal problem seems to be not how to measure the quantities involved, but rather how to determine the best quantities to measure. Gloss is associated with the ability of objects to reflect light specularly. The structural properties of objects responsible for specular reflection and the glossiness of these objects which results from specular reflection can be described at some length; but the specular reflectance itself, for most objects, cannot be measured because it cannot be separated in any but an approximate way from the diffuse reflectance. Reflection-distribution functions, though complex and cumbersome, offer the only means by which the reflectance properties of surfaces responsible for their glossiness may be completely specified.

Different types of gloss may be classified according to their appearance characteristics. Six types are identified in the present paper, as follows: (1) specular gloss, identified by surface shininess; (2) sheen, identified by surface shininess at grazing angles; (3) contrast gloss, identified by contrasts between specularly reflecting areas of surfaces and other areas; (4) absence-of-bloom gloss, identified by the absence of excess reflection (haze or smear) adjacent to reflected high lights; (5) distinctness-of-reflected-image gloss, identified by the distinctness of images reflected in surfaces; and (6) absence-of-surface-texture gloss, identified by the lack of surface texture and points of fixation which locate the surface. If the designs of existing gloss meters are examined they will usually be found to measure one or more of the above types of gloss. The primary requirement for each of these gloss meters is that, when applied to specimens of the type for which it is intended, it shall give results which correlate satisfactorily with gloss ratings on the same specimens assigned by visual grading. In order to describe gloss meters so that the measurements they make may be reproduced, it is necessary to specify precisely the apparent-reflectance measurement made. Each type of gloss is considered separately and the devices by which each may be measured described. Goniophotometric data provide a basis for the design and improvement of gloss-determining devices.

XIII. BIBLIOGRAPHY ON GLOSS

Because gloss literature has originated in so many sources and appeared in connection with work in so many different fields, it has been thought worth while to make this bibliography on gloss as complete as possible. Listed in parentheses following each reference below are (1st parentheses) the type of gloss or phase of the subject treated and (2d parentheses) the materials and types of specimens studied.

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