INTERNATIONAL STANDARD ISO 5

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION •МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Photography — Determination of diffuse transmission density

Photographie — Détermination de la densité optique en lumière diffuse

First edition — 1974-10-15

UDC 771.534.531.5 **Ref. No. ISO 5-1974 (E)**

Descriptors : photography, black and white photography, photographic film, photographic plates, calibrating, photometry, flux density, radiant flux density, transmission.

Price based on 19 pages

ISO 5-1974 (E)

FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO Member Bodies). The work of developing International Standards is carried out through ISO Technical Committees. Every Member Body interested in a subject for which a Technical Committee has been set up has the right to be represented on that Committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

Prior to 1972, the results of the work of the Technical Committees were published as ISO Recommendations; these documents are now in the process of being transformed into International Standards. As part of this process, Technical Committee ISO/TC 42 has reviewed ISO Recommendation R 5 and found it suitable for transformation. International Standard ISO 5 therefore replaces ISO Recommendation R 5-1954.

ISO Recommendation R 5 was approved by the Member Bodies of the following countries :

Australia	France	Sweden
Austria	Italy	Switzerland
Belgium	Mexico	United Kingdom
Chile	Netherlands	U.S.A.
Czechoslovakia	Poland	Yugoslavia
Denmark	Portugal	
Finland	South Africa, Rep. of	

No Member Body expressed disapproval of the Recommendation.

The Member Body of the following country disapproved the transformation of ISO/R 5 into an International Standard :

United Kingdom

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Photography — Determination of diffuse transmission density

0 INTRODUCTION

0.1 Discussion of density and explanation of terms

Transmission density is defined in general terms as the common logarithm of the ratio of the radiant flux incident on the sample to the radiant flux transmitted by the sample.

When radiant flux is incident on an exposed and processed photographic film or plate, part of the flux is reflected, part is absorbed, and part is transmitted, the transmitted flux usually being scattered. In practice the receiver may collect all or only a portion of the transmitted flux depending on the nature of the receiver and its position relative to the sample. Similarly, as the sample is removed, the receiver may collect all or only a portion of the incident flux. Moreover, the incident flux may be diffuse, or semi-diffuse, or it may be a parallel beam incident at an angle.

Considering some of these possible variations in the geometrical arrangement of the optical system alone, it is apparent that a multiplicity of numerical values of density can be obtained for a given sample depending on how the measurements are made. In any specified geometric condition the effective value of density will also depend on both the colour quality of the light and the colour sensitivity of the receiver, if the sample is spectrally selective. To avoid confusion it is desirable to standardize certain specific methods of measurement.

The problem of establishing a standard of density can be divided into two parts :

a) Specification of the geometric characteristics of the optical system used in the measurement.

b) Specification of the spectral sensitivity of the receiver and the spectral energy distribution of the radiant flux incident on the sample.

Variations in the geometrical arrangement of the optical system give rise to a number of geometric types of density which generally lead to different numerical density values. Among these are found three distinct and fundamental types :

a) Diffuse density,

b) Specular density,

c) Doubly diffuse density.

0.1.1 Diffuse density is obtained when the radiant flux is incident normally on the sample and all of the transmitted flux is collected and equally evaluated. The phrase "collected and equally evaluated" means that the effect on the receiver of all the rays transmitted by the specimen is the same regardless of the angle of emergence. Experimental studies show that the same results are obtained when the incident radiant flux is perfectly diffuse and the specularly transmitted component is collected and evaluated.

0.1.2 Specular density results when the radiant flux is incident normally on the sample and only the normal component of the transmitted flux is collected and evaluated.

0.1.3 Doubly diffuse density is obtained when the radiant flux incident on the sample is completely diffuse and all of the transmitted flux is collected and equally evaluated.

These three types of density are discussed more fully in the annex.

This International Standard is concerned only with diffuse density. This type of density is closely related to many practical applications of photographic materials (see the annex). The characteristics of photographic films are frequently expressed in terms of diffuse density and the term is often used in photographic literature, but it is seldom defined precisely. This International Standard provides a definition (see clause 3) for this type of density and introduces the term "totally diffuse density" as a means of indicating that all of the light is collected.

In totally diffuse density the incident radiant flux is **normal** to the plane of the sample, and all of the transmitted flux is collected and equally evaluated; or, the incident flux is perfectly diffuse and only the normally transmitted flux is collected and evaluated. Moreover, the term signifies that the effects of reflections between the sample and any part of the apparatus (cover glasses, surfaces of the receiver or illuminator, etc.) are negligible and that stray radiation, room light, etc. are excluded.

When the density of photographic films or plates is measured, the diffusion requirements are better satisfied if the emulsion side of the sample faces the receiver which is to collect the transmitted flux. When the incident radiation is diffuse, the emulsion side of the sample should face the diffuser.

The conditions required for the measurement of totally diffuse density cannot be met perfectly, but can be approached very closely, in instruments and apparatus designed for the purpose.

Since the theoretically ideal conditions for totally diffuse density are never met perfectly in practice, the term "ISO Standard diffuse density" has been chosen to designate densities which have been determined under the practical geometric conditions provided by the apparatus and methods specified in this International Standard. The specified apparatus and methods are especially appropriate, however, since they give values of density so closely approaching totally diffuse density that no errors of practical significance arise when the apparatus is constructed and used as specified in this International Standard.

For a sample which is spectrally nonselective the specification of the geometric conditions is sufficient since this specification will lead to a unique value of density. However, for samples which are spectrally selective, it is necessary to consider, in addition, the spectral conditions.

Variations in the spectral conditions give rise to a number of spectral types of density for any given geometric type. Although other important uses of photographic silver images are found in practice, photographic films and plates are usually either viewed by the human eye or printed on positive photographic materials. Therefore, this International Standard specifies in detail only two spectral types of diffuse density, namely :

Diffuse visual density, Type V1-b

Diffuse printing density, Type P2-b

The significance of these terms will be clarified by reference to the density chart in the annex.

The term "visual" is used to indicate that the receiver of the transmitted flux is either the human eye or has a spectral sensitivity equal to it. In the first classification the term "Type V1-b" indicates that the spectral conditions have been particularized even further. Type V1 refers to the spectral sensitivity of the average normal human eye, a representative curve for which has been standardized by the International Commission on Illumination. The "b" in Type V1-b refers to the spectral energy distribution of the incident radiant flux and indicates that the spectral quality is that of a tungsten lamp operating at a colour (distribution) temperature of 3 000 K.

Similarly, in the second classification, the term "printing" is used to indicate that the receiver of the transmitted flux is either the photographic printing material or has a spectral sensitivity equal to it. Type 2, used in connection with printing density, refers to a spectral-sensitivity curve representative of commonly used photographic printing papers. This spectral sensitivity is specified in detail in this International Standard. The "b" in Type P2-b again refers to the spectral energy distribution of the incident radiant flux and indicates that the spectral quality is that of a tungsten lamp operating at a colour (distribution) temperature of 3 000 K.

"Diffuse photoelectric density" and "diffuse spectral density"[1] (diffuse density for a single wavelength) designate other spectral classes of diffuse density which are not covered in detail in this International Standard. These spectral classes of density are, however, important in certain practical work. Their relation to this International Standard is described in the annex and illustrated in figure 12.

0.2 Calibration of practical densitometers

With the establishment of this International Standard it becomes practicable to calibrate a number of photographic samples by one of the approved measuring methods and to use these as reference specimens for calibrating ordinary densitometers.

In general only those densitometers which conform to the geometric and spectral conditions specified in this International Standard are capable of giving accurate readings of ISO Standard diffuse visual density or ISO Standard diffuse printing density for all types of photographic materials. However, many simple densitometers give readings on different photographic materials with sufficient accuracy for most practical work. The scope of such instruments can be tested by measuring samples which vary in scattering power and in spectral selectivity and comparing these results with those obtained by the appropriate recommended method.

1) See Report of Committee on Colorimetry, *Journal of the Optical Society of America*, 34, 4, 188, Section 8, "Transmittance, Opacity and Density".

If a nonconforming densitometer is to be used for a large amount of routine work in connection with a given type of photographic material, it may be calibrated from reference samples or a reference wedge composed of the same material. In this way any type of densitometer can be calibrated to read ISO Standard diffuse visual density or ISO Standard diffuse printing density for any single type of photographic material, to a degree of accuracy commensurate with the stability and reproducibility of the instrument itself. In general, a new calibration must be made if accurate readings are desired on a different photographic material when a nonconforming densitometer is used.

1 SCOPE AND FIELD OF APPLICATION

This International Standard defines diffuse transmission density and specifies techniques for its measurement.

It applies primarily to processed black-and-white photographic films and plates, although it can also be applied to other radiation-absorbing media such as cast colloidal carbon-gelatin tablets or filters, filters consisting of dyes in gelatin, glass filters, or various types of radiation-absorbing screens used in photographic work where diffuse-density measurements are desired.

2 GENERAL DEFINITION OF DENSITY

Density is defined in general terms as the logarithm of the ratio of the radiant flux P_0 incident on the sample to the radiant flux P_t transmitted by the sample.

$$D = \log\left(\frac{P_0}{P_t}\right) \qquad \ldots (1)$$

3 TOTALLY DIFFUSE DENSITY

3.1 Definition

Totally diffuse density is defined by the expression in clause 2 when the following conditions are fulfilled :

3.1.1 *Geometric conditions*

3.1.1.1 The incident radiant flux shall be normal (at an angle of 90°) to the plane of the sample and all of the transmitted radiant flux shall be collected and equally evaluated; or the incident radiant flux shall be perfectly diffuse and only the normally transmitted component shall be collected and evaluated.

3.1.1.2 The effects of reflections between the sample and parts of the apparatus (cover glasses, surfaces of the illuminator or collector, etc.) shall be negligible.

3.1.1.3 Stray radiation shall be negligible.

3.1.2 *Spectral conditions*

Any spectral conditions may be associated with totally diffuse density. The geometric conditions can usually be fulfilled independently of the spectral conditions. If the sample is spectrally nonselective, the specification of the geometric conditions is sufficient for the unique evaluation of density.

4 ISO STANDARD DIFFUSE DENSITY

4.1 Definition

The term "ISO Standard diffuse density" designates densities determined under the practical geometric conditions provided by any one of the following three standard means and methods. These conditions approach the ideal conditions for totally diffuse density given in 3.1.1 as closely as practical equipment and methods permit.

4.1.1 The integrating sphere method is described in detail in clause 7.

4.1.2 The opal glass method is described in detail in clause 8.

4.1.3 The contact printing method is described in detail in clause 9.

4.2 Spectral conditions

Any spectral conditions may be associated with ISO standard diffuse density.

5 ISO STANDARD DIFFUSE VISUAL DENSITY

5.1 Definition

ISO Standard diffuse visual density, Type V1-b, is a particular spectral type of ISO Standard diffuse density and is defined by the expression in 4.1 when the following spectral conditions are fulfilled :

5.1.1 The product of the relative spectral sensitivity of the receiver of the radiant flux times the relative energy of the incident radiant flux at each wavelength shall be proportional to the product of the sensitivity and energy given in logarithmic form in column 4 of table 1.

5.1.2 The tolerances on the spectral characteristics of the system shall be such that the resulting numerical values of density will not be significantly different from those which would be obtained if the spectral requirements were perfectly met.[1)]

5.1.3 The relative sensitivity values given in logarithmic form in column 2 of table 1 are those adopted by the International Commission on Illumination, for the average normal human eye adapted to photopic vision.

5.1.4 The relative energy values given in logarithmic form in column 3 of table 1 are for a tungsten lamp operating at a colour (distribution) temperature of 3 000 K.

5.1.5 These requirements permit the use of filters in combination with various sources and receivers provided that the overall spectral characteristics of the combination conform with those specified in column 4 of table 1.

TABLE 1 – **Spectral conditions for ISO Standard diffuse visual density Type V1-b**

1	2	3	4
Wavelength nm	log (Relative sensitivity*)	log (Relative energy)	log (Relative sensitivity times energy)
400	0,00	0,00	0,00
420	1,00	0,14	1,14
440	1,76	0,27	2,03
460	2,18	0,38	2,56
480	2,54	0,47	3,01
500	2,91	0,56	3,47
520	3,25	0,63	3,88
540	3,38	0,70	4,08
560	3,40	0,76	4,16
580	3,34	0,81	4,15
600	3,20	0,86	4,06
620	2,98	0,90	3,88
640	2,64	0,94	3,58
660	2,18	0,97	3,15
680	1,63	1,00	2,63
700	1,01	1,02	2,03

* For the purposes of this International Standard the relative spectral sensitivity of the receiver is defined in general terms as the reciprocal of the relative energy necessary to produce a given response.

6 ISO STANDARD DIFFUSE PRINTING DENSITY

6.1 Definition

ISO Standard diffuse printing density, Type P2-b, is one spectral type of ISO Standard diffuse density and is defined by the expression in 4.1 when the following spectral conditions given in 6.1.1 are fulfilled.

6.1.1 The product of the relative spectral sensitivity of the receiver of the radiant flux at each wavelength times the relative spectral-energy distribution of the radiant flux incident on the sample shall be proportional to the product of sensitivity and energy given in logarithmic form in the last column of table 2.

6.1.2 The tolerance on the log relative sensitivity times energy values in column 4 of table 2 shall be such that the resulting numerical values of density will not be significantly different from those which would be obtained if the spectral requirements were perfectly met.

6.1.3 The relative sensitivity values given in logarithmic form in column 2 of table 2 will be the logarithm of the product of an average of the relative spectral sensitivities of commonly used photographic printing materials times the transmission of an ultra-violet absorbing filter which has a sharp cut-off at 360 nm. The filter has been included in order to minimize errors which might arise because of the uncertain transmission of glass optics at short wavelengths and the transmission band of silver deposits at 320 nm.

6.1.4 The log relative energy values given in column 3 of table 2 are for a tungsten lamp operating at a colour (distribution) temperature of 3 000 K.

6.1.5 The use of filters in combination with various sources and receivers is permissible provided the overall spectral characteristics of the combination conform with those given above.

6.1.6 The integrating sphere method (see clause 7) and opal glass method (see clause 8) actually measure **simulated** ISO Standard diffuse density. The contact printing method (see clause 9) is a **direct** method for measuring ISO Standard diffuse printing density (not simulated).

When the requirements of this International Standard are followed for integrating sphere and opal glass measurements, the resulting values of printing density (simulated) will be equal to those that can be obtained directly using the contact printing method. However, in the interest of simplicity, the word "simulated" has not been used throughout this International Standard when referring to printing density measurements made using the integrating sphere and opal glass methods.

1) When the samples are spectrally nonselective, the product of the energy of the source and the sensitivity and energy of the receiver and source actually used is not critical and may depart widely from values given in the column headed "log relative sensitivity times energy" given in table 1 without significantly affecting the results. Since photographic films and plates developed in ordinary, nonstaining developers are often sufficiently nonselective, the spectral conditions given in table 1 need not be in close agreement with the ideal values. However, the measurement of the effective density of a sharp-cutting yellow colour filter, for example, will require relatively close agreement with the ideal spectral values given in table 1.

TABLE 2 – **Spectral conditions for ISO Standard diffuse printing density Type P2-b**

1	2	3	4
Wavelength nm	log (Relative sensitivity*)	log (Relative energy)	log (Relative sensitivity times energy)
340	2,00	0,00	2,00
350	3,94	0,11	4,05
360	4,77	0,22	4,99
370	4,94	0,31	5,25
380	5,00	0,40	5,40
390	5,00	0,48	5,48
400	4,98	0,56	5,54
410	4,94	0,64	5,58
420	4,90	0,71	5,61
430	4,84	0,77	5,61
440	4,76	0,83	5,59
450	4,66	0,88	5,54
460	4,52	0,94	5,46
470	4,35	0,99	5,34
480	4,13	1,03	5,16
490	3,85	1,08	4,93
500	3,44	1,12	4,56
510	2,81	1,15	3,96
520	2,18	1,19	3,37
530	1,55	1,22	2,77
540	0,00	1,26	1,26

* For the purposes of this International Standard the relative spectral sensitivity of the receiver is defined in general terms as the reciprocal of the energy necessary to produce a given response. In the case of photographic receivers used in this particular International Standard, the spectral sensitivity shall be measured in terms of the reciprocal of the energy necessary to produce a reflection density equal to that used in the photographic photometry of 9.3.6 (null point check). This reflection density corresponds approximately to a point on the density-log exposure curve of the photographic material where the gradient is a maximum (see figure 7). This measurement of sensitivity is intended primarily for use in this International Standard, and may not be applicable in other problems.

7 INTEGRATING SPHERE METHOD

7.1 General

This method is approved because it provides means for measuring density either visually or objectively with a high degree of reproducibility and gives ISO Standard diffuse density values directly. The integrating sphere method has been described in the literature.[1)]

The integrating sphere, made and used according to the following specifications, provides the desired geometric conditions. Modulation of the radiant flux is effected by means of either the photometric inverse square law (figure 1) or the Martens type polarization photometer (figure 2). The method is approved for the measurement of ISO Standard diffuse density with the following specifications.

7.2 Apparatus

7.2.1 The diameter of the sphere shall be greater than 90 mm (3.5 in).

7.2.2 The sum of the areas of the openings in the sphere shall be less than 2 % of the area of the sphere wall.

7.2.3 The aperture at the sample shall be bounded by knife edges so as not to hinder light from reaching the sample area at grazing angles of incidence.

7.2.4 The screen used inside the sphere shall be elliptical and just large enough to shield the light spot in the sphere from the sample.

7.2.5 The interior wall of the sphere shall be coated with two coats of a suitable integrating sphere paint[2)] applied over a flat white undercoat of oil paint.

7.2.6 The diffusion coefficient[3)] of the sphere shall be 0,98 to 1,02.

7.2.7 Angular deviation from normal of the light collected by the receiver shall not exceed 10°.

7.2.8 Suitable lamp houses, diaphragms, and shields shall be used to reduce stray radiation to such an extent that its effect is negligible.

1) "Standardization of Photographic Densitometry", Clifton Tuttle and A. M. Koerner, *Journal of the Society of Motion Picture Engineers XXIX, No. 6,* December, 1937.

2) A suitable integrating sphere paint produces a highly reflective and diffusing surface which is spectrally nonselective. A paint composed of titanium dioxide pigment concentrated in a clear vehicle is considered suitable for this purpose.

3) The diffusion coefficient is the ratio *A/B,* where *A* is the area under the curve obtained by plotting the relative luminous intensity of the exit aperture of the sphere as a function of the angle of view over the range of 0° to 180°, and *B* is the area under the corresponding curve for a perfect diffuser. Relative luminous intensity at any angle of view is expressed as a fraction of the luminous intensity measured at the normal angle (90°).

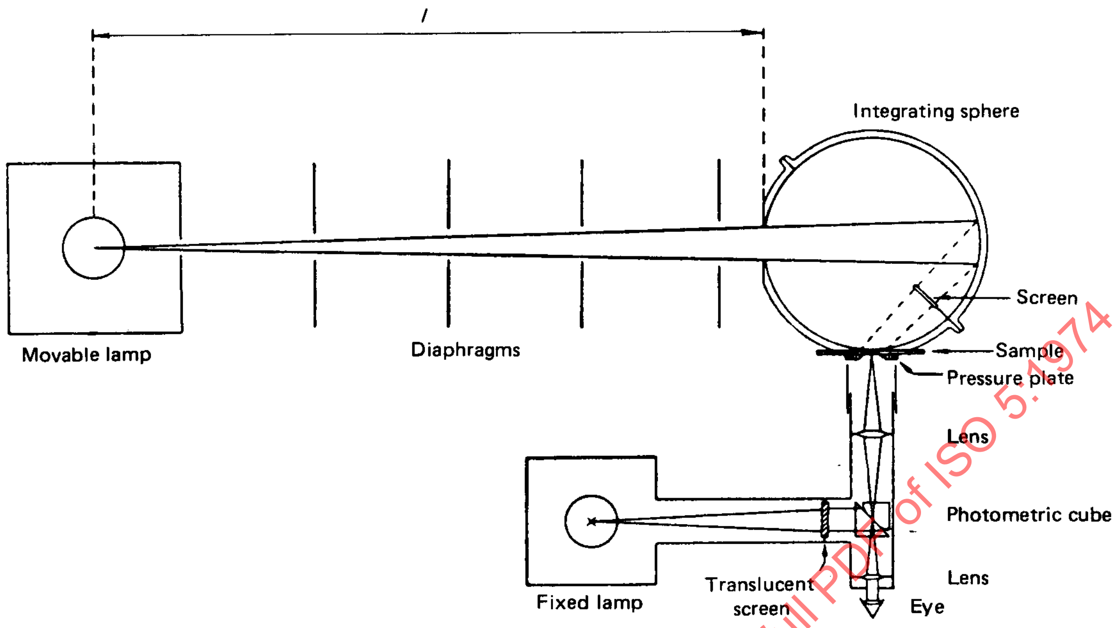

FIGURE 1 – **Apparatus for integrating sphere method using inverse square law**

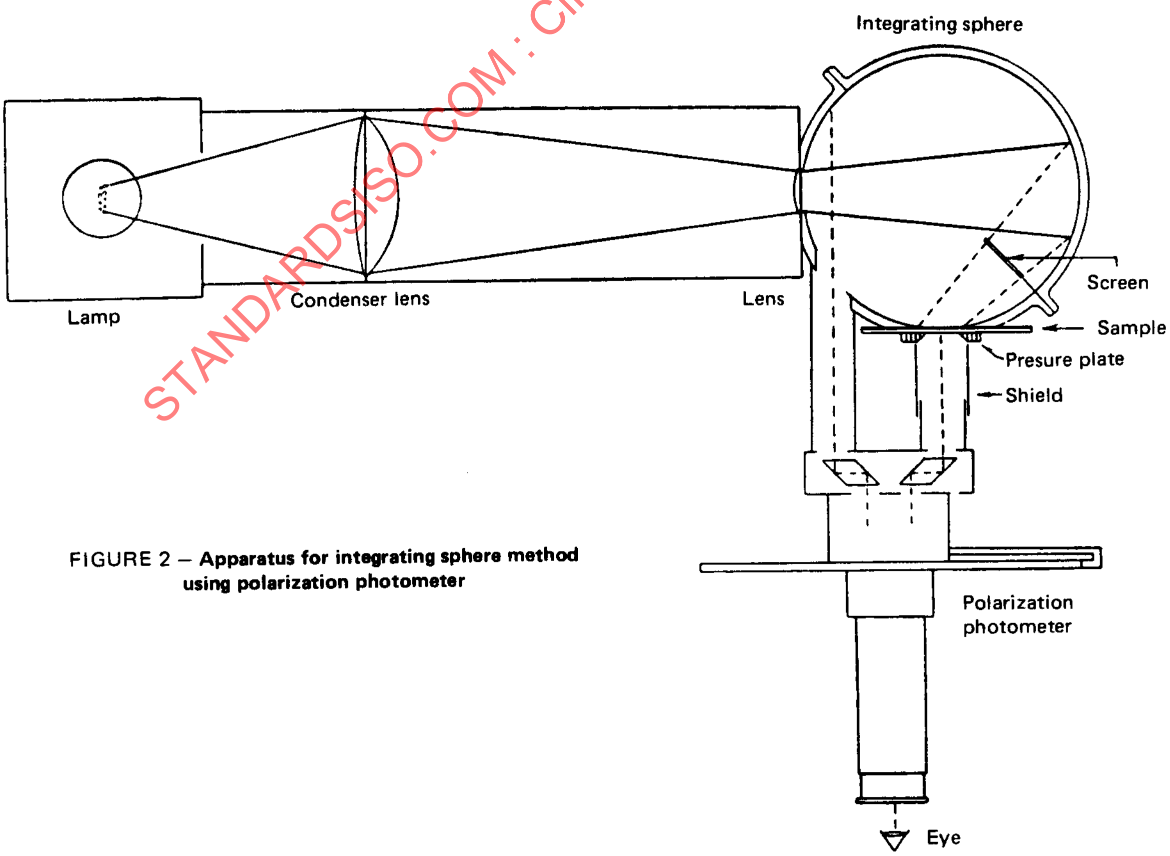

FIGURE 2 – **Apparatus for integrating sphere method using polarization photometer**

7.2.9 The source of radiation shall be sufficiently intense for the flux reaching the receiver to be adequate for efficient operation. For visual work the luminance of the photometric field shall be not less than 3,4 cd/m^2 (3,4 nits). The spectral energy distribution of the radiation from the source shall be appropriate to the spectral type of density desired. See 4.1, 5.1.1 and 6.1.1.

7.2.10 The receiver of the flux shall be a suitable radiation-sensitive device having a spectral sensitivity appropriate to the spectral type of density desired. See 4.1, 5.1.1 and 6.1.1.

7.2.11 Auxiliary apparatus for work in conjunction with the photometric inverse square law shall include a straight track or photometric bench on which to move the source of radiation in a straight line, lying on the optical axis of the sphere (see figure 1). The length of the track shall be not less than 2 m and shall be great enough to permit the measurement of the distance from the source to the sphere with an accuracy of ± 0,2 %. In no case shall the source be used nearer the sphere than 10 times the greatest linear dimension of the source or the aperture through which the light enters the sphere. The ratio of the intensity of the comparison source to that of the main source shall be constant to within ± 0,4 %. In cases where the eye serves as the receiver, the spectral quality of the radiation from the comparison source shall be such that when it is used with the translucent diffusing screen as shown in figure 1, the spectral quality of the radiation emitted by the screen will be approximately equal to that of the radiation emitted by the sphere when no sample is present. It is permissible to use a filter in combination with the translucent screen in order to achieve the desired equality in spectral composition.

7.2.12 A Lummer-Brodhun type photometric cube[1] is recommended for visual work in conjunction with the inverse square law.

7.2.13 When the Martens type polarization photometer is used with the integrating sphere, the general arrangement of parts shown in figure 2 shall be followed. The lens system between the source and the sphere is not essential but it is recommended since it gives an increase in the brightness of the photometric field without an increase in the size of the area covered by the beam on the sphere wall. Any clear bulb tungsten lamp which is operated under such conditions as to give a colour (distribution) temperature of 3 000 K may be used.[2]

7.3 Procedure when inverse square law is used

7.3.1 Precautions shall be taken to prevent stray radiation from entering the sphere, from falling on the sample, or from entering the photometric cube.

7.3.2 With no sample in the beam the movable source (see figure 1) shall be set at a distance, l_0, such that the two halves of the photometric field are balanced. The intensity of the comparison field shall be adjusted so that l_0 is not less than 2 m.

7.3.3 The sample shall be placed over the exit aperture of the sphere, and in the case of photographic films or plates, the emulsion surface shall be in contact with the sphere. The movable source shall then be moved toward the sphere, to a distance, l_s, at which the two halves of the photometric field are equal.

7.3.4 The density of the sample shall then be computed from formula (1) of clause 2 :

$$D = \log\left(\frac{P_0}{P_t}\right)$$

where

$$\frac{P_0}{P_t} = \frac{l_0^2}{l_s^2} \qquad \text{. . . (2)}$$

7.3.5 The value of l_0 used in the above formula shall be the average of not less than five separate readings of l_0, each of which involves a redetermination of the photometric balance. Similarly, not less than five separate readings shall be made and averaged to determine the value of l_s used in the above formula.

7.3.6 In determining densities above 2,0 it is permissible to use an auxiliary density to make possible the reading of high densities without recourse to an inconveniently long photometric bench. The auxiliary density shall be placed in the sample position and its density, D_a, determined using the procedure given above. With the auxiliary density left in this position the movable source of radiation shall be replaced by one of higher intensity (or the comparison source shall be lowered in intensity), its intensity being such that when it is placed near the end of the track, the photometric field will be balanced. The distance, l'_0, at which the balance occurs shall be obtained by averaging five independent settings. The auxiliary density shall then be removed, and the unknown (high density) sample shall then be substituted for it in the sample position. The movable lamp shall be brought nearer the sphere until a photometric balance is again obtained, the setting being repeated five times to give an average value of l'_s. The density of the sample is then computed from the formula

$$D = D_a + \log\left(\frac{l'_0}{l'_s}\right)^2 \qquad \text{. . . (3)}$$

7.4 Procedure for using the polarization photometer

7.4.1 With no sample in the beam, the angle θ_1 in quadrant I (see figure 3) which gives a photometric balance shall be read. Also the angle θ_2 in quadrant II which gives a

1) See Walsh, *Photometry,* Constable, p. 155, 1926 Edition, London.

2) A 500 W, 115 V bi-plane tungsten projection lamp is recommended when the sphere diameter is approximately 10 cm (4 in).

photometric balance shall be read. The difference between these two angles is ω_0, which is related to the difference in luminance between the two beams when no sample is present. (Reading the angle in two quadrants and taking the difference cancels any error which may exist in the adjustment of the index relative to the position of the planes of polarization in the interior of the photometer head.)

7.4.2 With the sample placed in the sample beam, in contact[1] with the diffuser, the angle θ_3 in quadrant I, which gives a photometric balance shall be read. The angle θ_4 in quadrant II, which gives a balance also shall be read. The difference between these two angles is ω_1, which is related to the difference in luminance between the two beams when the sample is present. (Again any error due to faulty adjustment of the zero setting of the index line is thereby cancelled.)

7.4.3 Each photometric balance shall be made not less than three times and the angular readings averaged to give each value which is to be used in determining ω_0 and ω_1 in 7.4.1 and 7.4.2. The transmittance of the sample shall be computed from the formula

$$\tau = \frac{\tan^2\left(\frac{\omega_1}{2}\right)}{\tan^2\left(\frac{\omega_0}{2}\right)} \qquad \ldots (4)$$

7.4.4 To correct for the effects of possible polarization in the sample, the transmittance also shall be determined after rotating the entire photometric head through 180° (without moving the sample) and using again the procedure given in 7.4.1, 7.4.2 and 7.4.3. The transmittance value to be used in computing the density of the sample shall be equal to the average, τ, of the two transmittance values obtained with the photometer head in the two positions.

7.4.5 The density of the sample shall then be computed from formula (1) of clause 2

$$D = \log\left(\frac{P_0}{P_t}\right)$$

where

$$\frac{P_0}{P_t} = \frac{1}{\tau} \qquad \ldots (5)$$

and τ is obtained from 7.4.4.

7.4.6 An auxiliary density shall be placed in the comparison beam when densities above 1,3 are to be measured. No change in the procedure given above need be made since the calibration of the auxiliary density is included in the determination of the value of ω_0 used in the computations. An auxiliary density of approximately 1,3 shall be used for reading sample densities lying between 1,3 and 3,0.

7.4.7 In some commercial forms of the polarization photometer the angular engravings on the scale do not extend into the quadrants III and IV. In some instruments, too, the scales are calibrated to read density or transmittance directly. These direct reading scales shall not be used in the determination of ISO Standard density since certain errors can be eliminated only by averaging angles and not by averaging densities or transmittances.

8 OPAL GLASS METHOD

8.1 General

This method has been included because it comprises a simple visual method of obtaining results which can be converted to ISO Standard diffuse density through the use of a conversion chart. The opal glass method illustrated in figure 4 is approved for the measurement of ISO Standard diffuse density provided that the correction curve shown in figure 5 is used to convert from values of opal glass density to values of ISO Standard diffuse density. The specifications are given in 8.2 and 8.3.

8.2 Apparatus

8.2.1 Total reflectance of the opal glass for normal illumination shall lie within 0,55 to 0,60.

8.2.2 Pot opal glass of the cryolite low-absorption type shall be used.

8.2.3 The diffusion coefficient[2] of the opal glass shall be 0,90 to 0,94.

8.2.4 The surface of the opal glass which faces the sample shall be smooth (polished), since a smooth surface is easy to keep clean, and shall be thoroughly clean when in use.

8.2.5 The surface of the opal glass which faces the sample shall be large enough to provide a uniformly bright, circular area not less than 1 cm in diameter. Areas of opal glass lying outside the specified circular area are permissible only if the sample is large enough to cover them.

1) In the case of photographic films or plates the emulsion side shall be in contact with the diffuser.

2) Method of Halbertsma : With light incident normally on the surface, the luminous intensities (relative to normal, in percent) at different angles of view, θ, are plotted as abscissae, the corresponding ordinates being proportional to $(1 - \cos\theta)$. For a perfectly diffusing surface the resulting curve is a straight line. The ratio of the area enclosed by the axes of co-ordinates and the representative curve for any surface to the area for a perfectly diffusing surface is termed the "diffusion coefficient" of the surface.

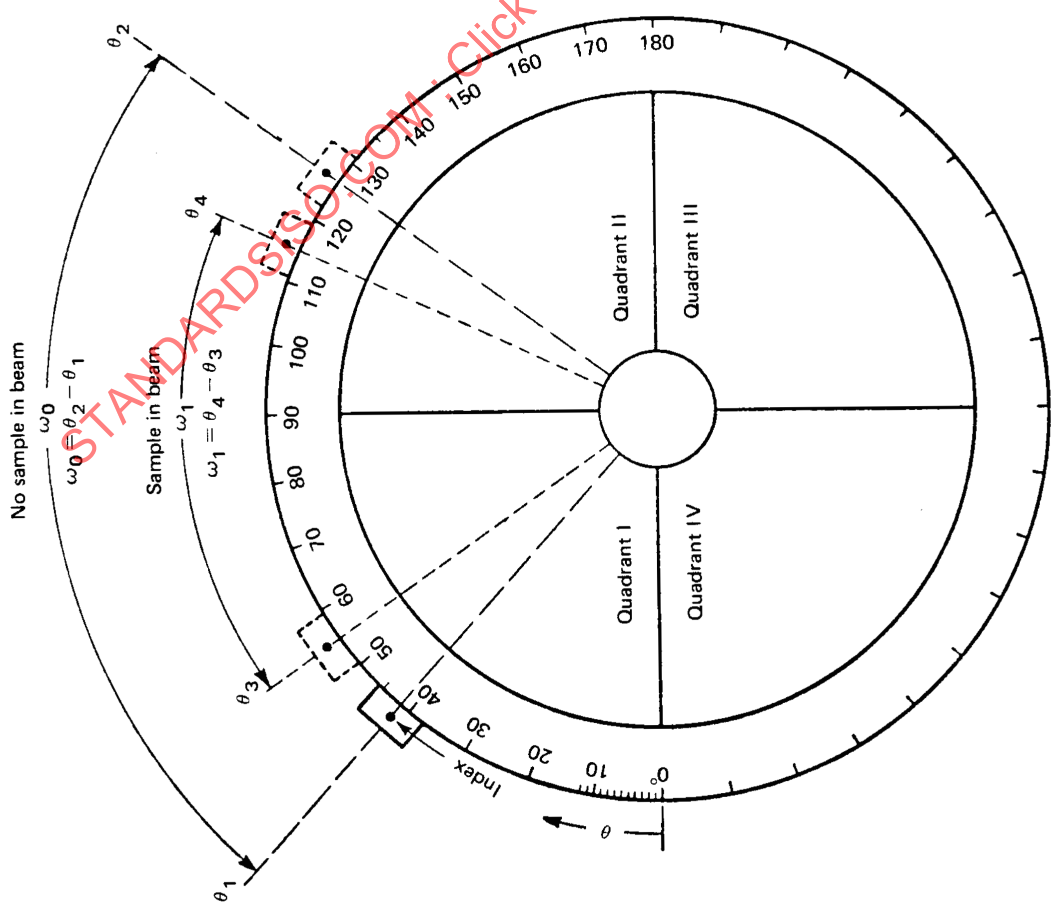

FIGURE 3 — **Martens polarization photometer scale**

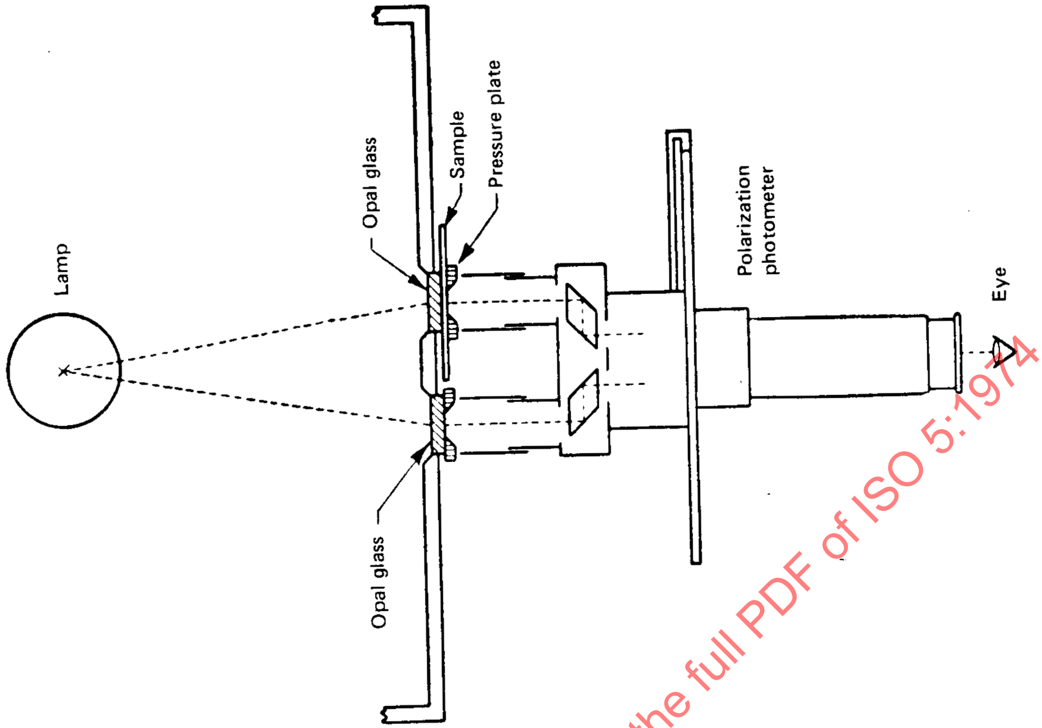

FIGURE 4 — **Apparatus for opal glass method**

8.2.6 The radiant flux on the opal glass may be either normal or diffuse (not critical).

8.2.7 The sample shall be placed in contact with the opal glass and shall be large enough to cover the exposed area of the opal glass. In cases where photographic films or plates are to be evaluated the emulsion surface shall be in contact with the opal glass.

8.3 Procedure

A Martens type polarization photometer shall be used according to the procedure given in 7.4. Density values shall be computed by means of the formula in 7.4.5. These densities will depart from ISO Standard diffuse densities by known amounts, owing to the inter-reflection effects and the diffusion characteristics associated with the pot opal glass diffuser. ISO Standard diffuse densities shall be obtained from the opal glass densities by means of the conversion chart shown in figure 5.

9 CONTACT PRINTING METHOD

9.1 General

This system is recommended because it provides an objective method for measuring the density of transmission samples by contact printing on ordinary photographic paper of specified characteristics and gives ISO Standard diffuse density values directly. Apparatus and test procedure have been developed and are described in the literature[1]. The apparatus is illustrated in figure 6. The inverse square law is employed and when this method is used, the geometric conditions required for the determination of ISO Standard diffuse density are fulfilled.

9.2 Apparatus

9.2.1 *Source of radiation*

The source of radiation shall have a spectral quality appropriate to the spectral type of density desired. See tables 1 and 2. The greatest linear dimension of the source shall be less than one-tenth of the minimum optical distance (from source to receiver) used[2]. All filters used in the system shall be placed at the source of radiation rather than at the receiver.

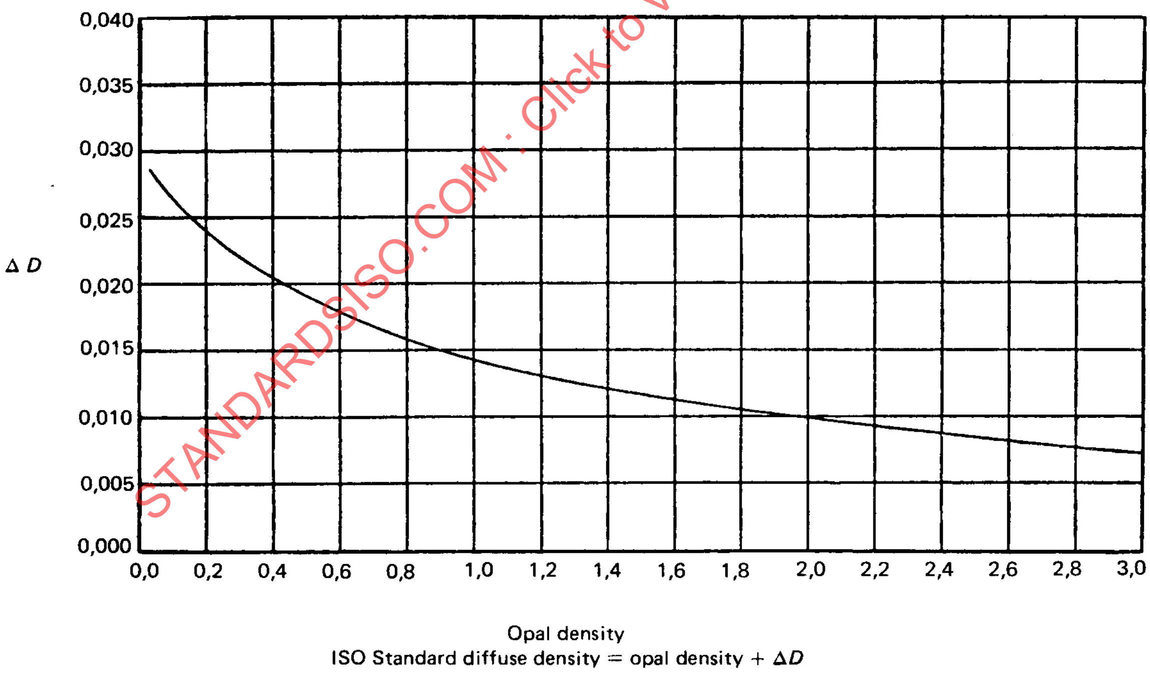

FIGURE 5 — **Conversion chart for obtaining ISO Standard diffuse density from opal density**

1) Monroe H. Sweet, "An Improved Procedure for the Contact Printing Method of Measuring Photographic Density", *Journal of the Optical Society of America*, 33 : 143-63, March 1943.

2) An opal glass, fitted with a mask having a circular aperture of such dimensions that the diameter of the aperture is less than one-tenth of the minimum optical distance used, forms a convenient source which meets the requirements (see figure 6).

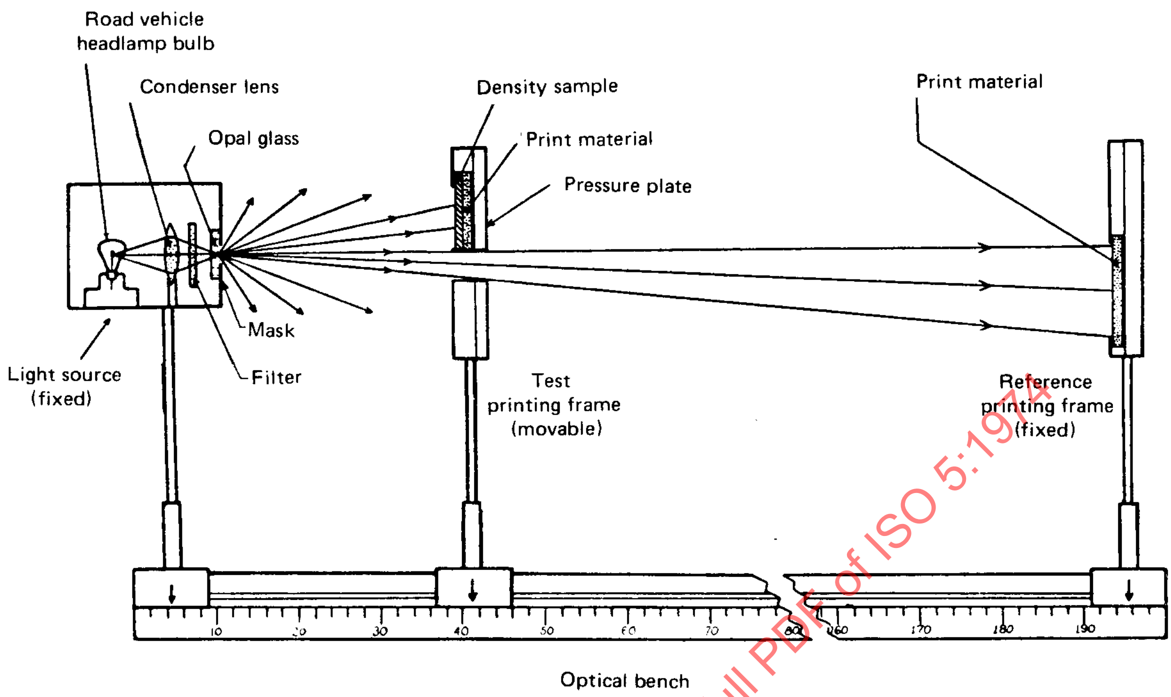

FIGURE 6 – **Apparatus for contact printing method**

9.2.2 *Receivers*

The receivers shall consist of two halves of a sheet of sensitized photographic material. One-half shall be mounted in a printing frame[1] in mechanical contact with the diffusing surface of the sample and facing the light source at right angles to the optical axis. The other half of the sheet shall be mounted at some greater distance from the light source and also at right angles to it. The sheets shall be so oriented in space that, when viewed from the light source, their common edge of separation shall appear coincident. The mounting frame which contains the density specimen shall be designed so that no significant amount of radiation is reflected by the edges of the frame to either half of the sheet of paper. Both pieces of the sensitized material shall be backed with an opaque white surface.

9.2.3 *Sensitized material*

9.2.3.1 The spectral sensitivity of the sensitized material shall be appropriate to the spectral type of density desired. See 4.1, 5.1.1 and 6.1.1.

9.2.3.2 For the determination of ISO Standard diffuse printing density, Type P2-b, the sensitized material shall consist of a white paper support coated with a glossy silver bromide emulsion having a reflection coefficient of 0,90 ± 0,05. The spectral sensitivity of the material shall be that specified in 6.1.1. A number of commercially available sensitized bromide printing papers will be found satisfactory.

9.2.4 *Optical bench*

The light source and receivers shall be mounted on an optical bench, or equivalent, of such construction that the distance from the light source to the first receiver can be determined to an accuracy of ± 0,2 %, and the distance from the source to the second receiver to within ± 0,1 %.

9.2.5 *Stray flux*

The stray flux reaching the receivers shall be restricted to less than 0,2 % of the incident beam by means of baffles of appropriate dimensions, suitably located.

9.2.6 *Control of exposure time*

Since this technique involves the null method, the exposure duration is not critical and the need for optical shutters is eliminated; exposures may be commenced and terminated by closing and opening the lamp circuit.

9.3 Procedure

9.3.1 *Location of the density specimens*

The photographic layer whose density is to be measured shall be placed emulsion to emulsion in mechanical contact with the sensitized surface of the first receiver. When the densities of other than photographic layers are to be measured, the diffusing surface shall be placed in contact with the sensitized surface of the receiver.

1) There shall be no cover glass used in the printing frames.

9.3.2 *Exposures*

9.3.2.1 An exposure shall be made with the second receiver located at the maximum distance from the light source permitted by the optical bench and with the first receiver at a shorter distance, chosen so as to produce a test print[1] density higher than that of the reference print. Two additional pairs of sheets shall be exposed with the first receiver in positions calculated to give test print densities approximately equal to and less than their reference prints respectively[2]. The change in relative exposure shall be accomplished by moving the test receiver along the bench, in increments which correspond to a log intensity change of 0,05.

9.3.2.2 In all cases the intensity and time of exposure should be such as to produce, upon development, a reference print density at, or near, the point on the D vs $\log H$ curve of the print material where the gradient is, or approaches, a maximum (see figure 7).

9.3.2.3 No ray from the source which makes an angle of more than 5° with the optical axis shall be used in the determination.

9.3.3 *Processing*

The exposed sheets shall be processed by any sensitometric method known to give uniform results[3]. Sheets of each pair shall be matched and secured immediately adjacent to one another during development, in positions which retain their original orientation.

9.3.4 *Reflection density readings*

After processing, the reflection densities of the individual prints shall be determined by means of any suitable reflection densitometer or comparator, the original orientation being maintained.

9.3.5 *Initial density calculation*

The approximate density of the specimen shall be calculated from the relationship between the reflection density of the test prints and the corresponding reference prints by interpolation of a curve plotted as density vs log exposure[4], or by any other convenient method. The following procedure is recommended :

9.3.5.1 The sensitometric characteristics of the print material are determined under exposure, processing, and density measuring conditions which conform with those used in the test. Figure 7 illustrates the manner in which a D vs $\log H$ curve is plotted.

9.3.5.2 The points on the curve of figure 7 which correspond to the densities of the test and reference prints of 9.3.2.1 are located on the D vs $\log H$ curve and their $\log H$ values determined.

9.3.5.3 For each pair of test and reference prints the values for D_x and $\log H$ are substitued in the following formula

$$D = D_x + \Delta \log H \qquad \ldots (7)$$

where

D is the transmission density of the specimen;

D_x is the density of a specimen for which the reference and test sheets would be identical at the same light-source to test-frame distance, X_0[5], used in 9.3.2.1;

$\Delta \log H$ is the $\log H$ value of the reference print minus the $\log H$ value of the test print.

The average for D determined from the three sets of test and reference sheets should be used as the initial density value of the specimen.

1) The piece of sensitized paper exposed in the first receiver shall be called the test sheet or print, and the receiver, the test receiver. Similarly, the sheet of sensitized paper exposed in the second receiver shall be referred to as the reference sheet or reference print, and the second receiver shall be referred to as the reference receiver.

2) The proper choice of test frame positions can be estimated by measurement of the approximate density of the sample on any ordinary densitometer and by applying the following formula :

$$\log X_0 = \log X_1 - \frac{D_p}{2} \qquad \ldots (6)$$

where

X_0 is the distance between the light source and test frame;

X_1 is the distance between the light source and the reference frame;

D_p is the estimated ISO Standard diffuse transmission density of the specimen.

3) Experience shows that brush development with sheets fastened to a glass plate gives uniform results.

4) Since some of the available printing materials have D vs log exposure gradients of 3,0 +, a change in log exposure of 0,01 produces a change in density of 0,03 +.

5) The relationship between D_x and X_0 is given in table 3, columns 1 and 2.

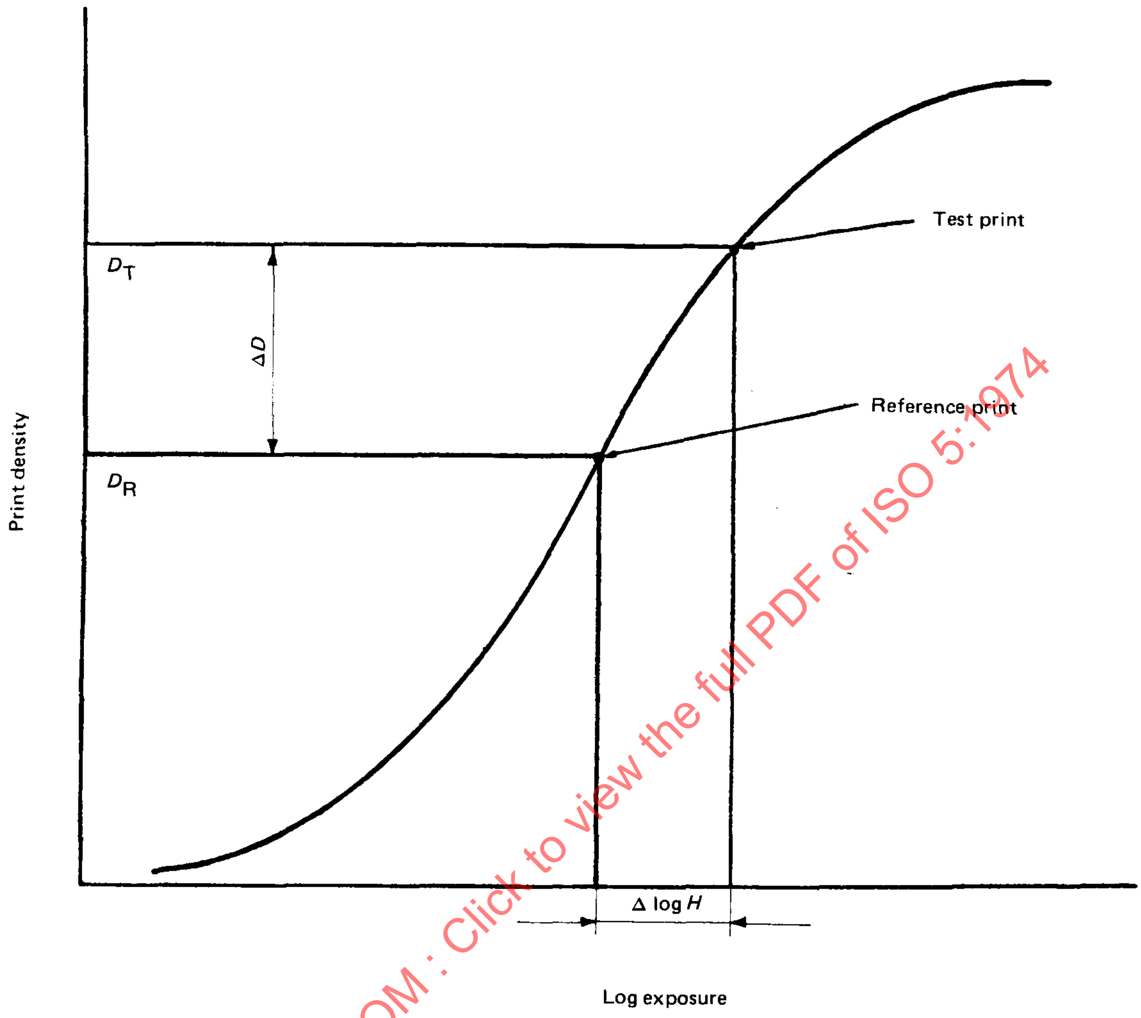

FIGURE 7 — *D* vs log *H* curve for a hypothetical paper used in the contact printing method

9.3.6 *Null point check*

9.3.6.1 Three or more additional exposures shall be made with the test receiver located at the position calculated (from formula 6 using the results of 9.3.5 which should give the same test and reference print densities). The final evaluation of the density shall be based on the relative distances of the reference receiver and the test receiver from the source which would result in identical test and reference print densities according to the relation :

$$D_p = 2 \log X_1 - 2 \log X_0 \qquad \ldots (8)$$

where

X_0 is the distance between the light source and the test frame;

X_1 is the distance between the light source and the reference frame;

D_p is the ISO Standard diffuse transmission density of the specimen.

9.3.6.2 The null point check described in 9.3.6.1 shall be repeated in every case wherein

a) the density value of the specimen computed from the null point check in question differs from the value previously assigned (on the basis of either the initial printing density test or a preceding null point check) by more than 0,005, or

b) the average difference in average deviation between the test and reference print densities is greater than 0,01.

9.3.7 *Alternative procedure for measuring high densities*

9.3.7.1 Specimen densities between 0,0 and 2,0 shall be measured directly as described in 9.3.1 to 9.3.6. Specimen densities between 2,0 and 4,0 may be measured by the following optional procedure which utilizes an expedient designed to eliminate the need for unduly long optical benches.

9.3.7.2 A specimen having a density value of approximately 2,0 shall be measured as to diffuse density according to the procedure covered by 9.3.1 to 9.3.6. This specimen shall be used as a comparison sample by placing it in the reference receiver and exposing the reference sheets through it. In all other respects, the same procedure shall be used as for 9.3.1 to 9.3.6, except that the exposure time or light source intensity, or both, shall be increased, in order to compensate for the increased attenuation of the radiation. The specimen density shall be computed by obtaining the nominal density value as described in 9.3.6 and adding to this value the density of the comparison sample.

9.4 Qualifying tests for apparatus and procedure

9.4.1 *Factor of merit*

In order that the point-to-point sensitivity of the receiver emulsion, the uniformity of processing, and the stability and sensitivity of the reflection densitometer or comparator be acceptable for use in the conduct of the standard procedure, the factor of merit, Z, determined as follows, shall have a value greater than 10.

9.4.1.1 Five sheets shall be cut in half and both halves of each sheet placed side by side in the reference receiver. They shall be exposed, one pair at a time, for the normal exposure time interval (that which yields the same reflection print densities as those used in the null point check), processed, and measured as to reflection density in the manner described in 9.3.4.

9.4.1.2 Five additional sheets shall be cut and exposed with one-half of each sheet placed in the reference receiver and the other half in the test receiver (but with no density specimen interposed). The test receiver shall be so located as to receive 0,05 log H greater flux density than the reference receiver (i.e., the source-test frame distance shall be 0,945 times the source-reference frame distance). These sheets shall be processed according to 9.3.3.

9.4.1.3 The average difference ΔD in reflection-instrument scale readings for all of the pairs of prints of 9.4.1.2 shall be divided by the average difference $\Delta D'$ between the instrument scale readings for the individual tests and reference prints of 9.4.1.1, giving a result which shall be the factor of merit.

$$Z = \frac{\Delta D}{\Delta D'} \qquad \ldots (9)$$

9.4.2 *Test for systematic errors*

In order to test an apparatus and procedure for systematic errors it is recommended that measurements on density specimens of suitable values be repeated using a light-source to reference-receiver distance which is some convenient fraction of the original. The null point positions of the test receiver will then be displaced by exactly the same factor if the systematic errors are negligible.

TABLE 3 – **Relationship between specimen density, D_x and relative light source to test frame distance X_0***

D_x	X_0	$\log X_0$	D_x	X_0	$\log X_0$
0,00	1,0000	0,000			
0,05	0,9441	$\bar{1}$,975	1,55	0,1679	$\bar{1}$,225
0,10	0,8913	$\bar{1}$,950	1,60	0,1585	$\bar{1}$,200
0,15	0,8414	$\bar{1}$,925	1,65	0,1496	$\bar{1}$,175
0,20	0,7944	$\bar{1}$,900	1,70	0,1413	$\bar{1}$,150
0,25	0,7499	$\bar{1}$,875	1,75	0,1334	$\bar{1}$,125
0,30	0,7080	$\bar{1}$,850	1,80	0,1259	$\bar{1}$,100
0,35	0,6683	$\bar{1}$,825	1,85	0,1189	$\bar{1}$,075
0,40	0,6310	$\bar{1}$,800	1,90	0,1122	$\bar{1}$,050
0,45	0,5957	$\bar{1}$,775	1,95	0,1060	$\bar{1}$,025
0,50	0,5624	$\bar{1}$,750	2,00	0,1000	$\bar{1}$,000
0,55	0,5309	$\bar{1}$,725	2,05	0,0944	$\bar{2}$,975
0,60	0,5012	$\bar{1}$,700	2,10	0,0891	$\bar{2}$,950
0,65	0,4732	$\bar{1}$,675	2,15	0,0841	$\bar{2}$,925
0,70	0,4467	$\bar{1}$,650	2,20	0,0794	$\bar{2}$,900
0,75	0,4217	$\bar{1}$,625	2,25	0,0749	$\bar{2}$,875
0,80	0,3981	$\bar{1}$,600	2,30	0,0708	$\bar{2}$,850
0,85	0,3759	$\bar{1}$,575	2,35	0,0668	$\bar{2}$,825
0,90	0,3548	$\bar{1}$,550	2,40	0,0631	$\bar{2}$,800
0,95	0,3350	$\bar{1}$,525	2,45	0,0595	$\bar{2}$,775
1,00	0,3163	$\bar{1}$,500	2,50	0,0562	$\bar{2}$,750
1,05	0,2986	$\bar{1}$,475	2,55	0,0530	$\bar{2}$,725
1,10	0,2819	$\bar{1}$,450	2,60	0,0501	$\bar{2}$,700
1,15	0,2661	$\bar{1}$,425	2,65	0,0473	$\bar{2}$,675
1,20	0,2512	$\bar{1}$,400	2,70	0,0446	$\bar{2}$,650
1,25	0,2371	$\bar{1}$,375	2,75	0,0421	$\bar{2}$,625
1,30	0,2239	$\bar{1}$,350	2,80	0,0398	$\bar{2}$,600
1,35	0,2114	$\bar{1}$,325	2,85	0,0376	$\bar{2}$,575
1,40	0,1995	$\bar{1}$,300	2,90	0,0355	$\bar{2}$,550
1,45	0,1884	$\bar{1}$,275	2,95	0,0335	$\bar{2}$,525
1,50	0,1778	$\bar{1}$,250	3,00	0,0316	$\bar{2}$,500

* Computed according to formula (6).

ANNEX

A.1 GEOMETRIC TYPES OF DENSITY

If parallel light is incident normally (perpendicularly) on a photographic film, and all of the transmitted light is collected and equally weighted in the measurement as shown schematically in figure 8a, a lower value of density will be obtained than if only the specularly transmitted light is collected and measured as shown schematically in figure 10a. These two types of density are known as "diffuse density" and "specular density". The first is called "totally diffuse density" in this International Standard to indicate that all of the diffuse light is collected and measured. The distinguishing modifier "totally" has been selected to set this specifically defined type of diffuse density apart from the loosely defined or undefined diffuse density commonly found in the literature. In practice, if a negative photographic film is contact printed on photographic paper using nearly parallel and normally incident light, as shown in figure 8b, its effective density may be identical with totally diffuse density illustrated in figure 8a.

A numerical value of density which is appreciably higher than totally diffuse density is obtained if completely diffuse light, as in figure 9a, is used to illuminate the sample, and all of the transmitted light is collected and equally weighted in the measurement. The increase over totally diffuse density is due to the fact that a higher percentage of the light rays traverse a longer path through the silver deposit. This type of density is termed "doubly diffuse density".

If a sheet of highly diffusing material is introduced in the contact printer in the position shown in figure 9b, the effective density of the negative film will be increased and will tend to equal doubly diffuse density illustrated in figure 9a. Many practical contact printers use a diffuser or a semi-diffuser in a manner similar to that shown in figure 9b. Many practical contact printers also use an extended light source consisting of a number of incandescent lamps and this tends to give density values which approach doubly diffuse density.

If the film is used in a specular type projector as shown in figure 10b, the effective density will usually be increased further and may agree approximately with specular density as illustrated in figure 10a. Many projection printers are only semi-specular so that the effective density of the film used in them is somewhere between specular density and totally diffuse density.

Another method of illuminating the sample and collecting the transmitted light is shown in figure 11. Completely diffuse light is incident on the sample but only the specularly transmitted beam is collected. Experimental and theoretical work show that the density obtained in this way will be the same as totally diffuse density.

The effective density of a film viewed on an opal glass illuminator approaches totally diffuse density. Small, known discrepancies occur, however, because of inter-reflections between the opal glass and the film.

The use of a cover glass over the density sample, either in making the measurements or in practical photographic work, has a small but measurable effect on the density value. In general, the effect of the cover glass is to increase the density by a small amount, approximately 0,025.

A.2 SPECTRAL TYPES OF DENSITY

In the above discussion only the geometric attributes of density have been discussed. In general, the numerical value of density will depend also on the relative spectral emission of the illuminant and the spectral sensitivity of the receiver. (In the unique case where the sample is spectrally nonselective, the spectral character of the source and the receiver will not influence the results.) Just as a large variety of geometric optical systems are used in photographic practice, numerous source-receiver spectral combinations are also to be found. For example, films intended for viewing are often examined under tungsten illumination at various colour (distribution) temperatures. Daylight, fluorescent light, carbon arc light, and other sources are sometimes used.

In common practice photographic films and plates are usually either viewed by the human eye or printed on positive photographic materials. Other important uses for photographic silver images are, of course, found in practice such as the use of films to modulate a light beam in sound recording or the use of films and plates in the field of astronomy and spectrum analysis in which measurements are often made on the developed photographic image by means of photoelectric equipment. In certain other types of work the density at a single wavelength of radiation is used. In these cases the visual or printing densities of the deposits may be of little interest.

At present, however, only two spectral types of density are specified in detail, namely :

1 Visual density, and

2 Printing density.

These differ only with respect to the spectral sensitivity of the receiver of the transmitted radiant energy.

The receiver for 1 is the human eye, the spectral sensitivity of which is known and specified.

The receiver for 2 is a photographic material, the spectral sensitivity of which is also known and specified.

Two additional spectral types of density are useful in practical work and they have been included in the general classification of density even though they are not specified in detail at the present time. These are :

3 Photoelectric density, and

4 Spectral density (density for any given wavelength).

The above classification of the spectral types of density is intended to be general in character. The spectral sensitivities of the receivers and the spectral distribution of the radiant energy incident on the sample have not yet been specified in detail.