INTERNATIONAL STANDARD 5

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Photography — Determination of diffuse transmission density

Photographie — Détermination de la densité optique en lumière diffuse

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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

Printed in Switzerland

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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.

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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°).

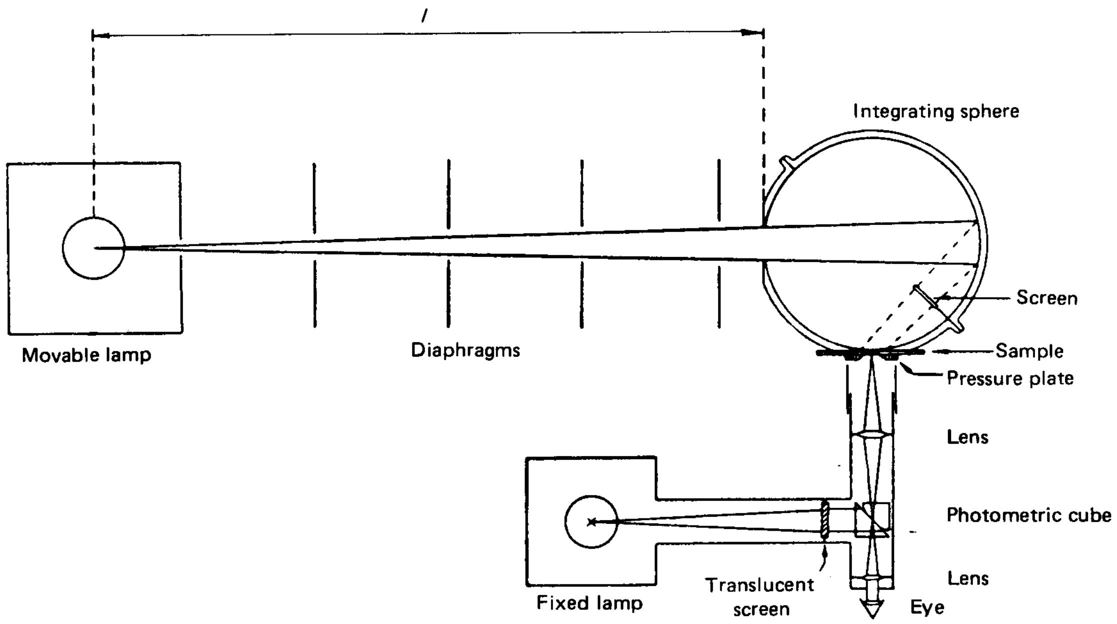

FIGURE 1 – **Apparatus for integrating sphere method using inverse square law**

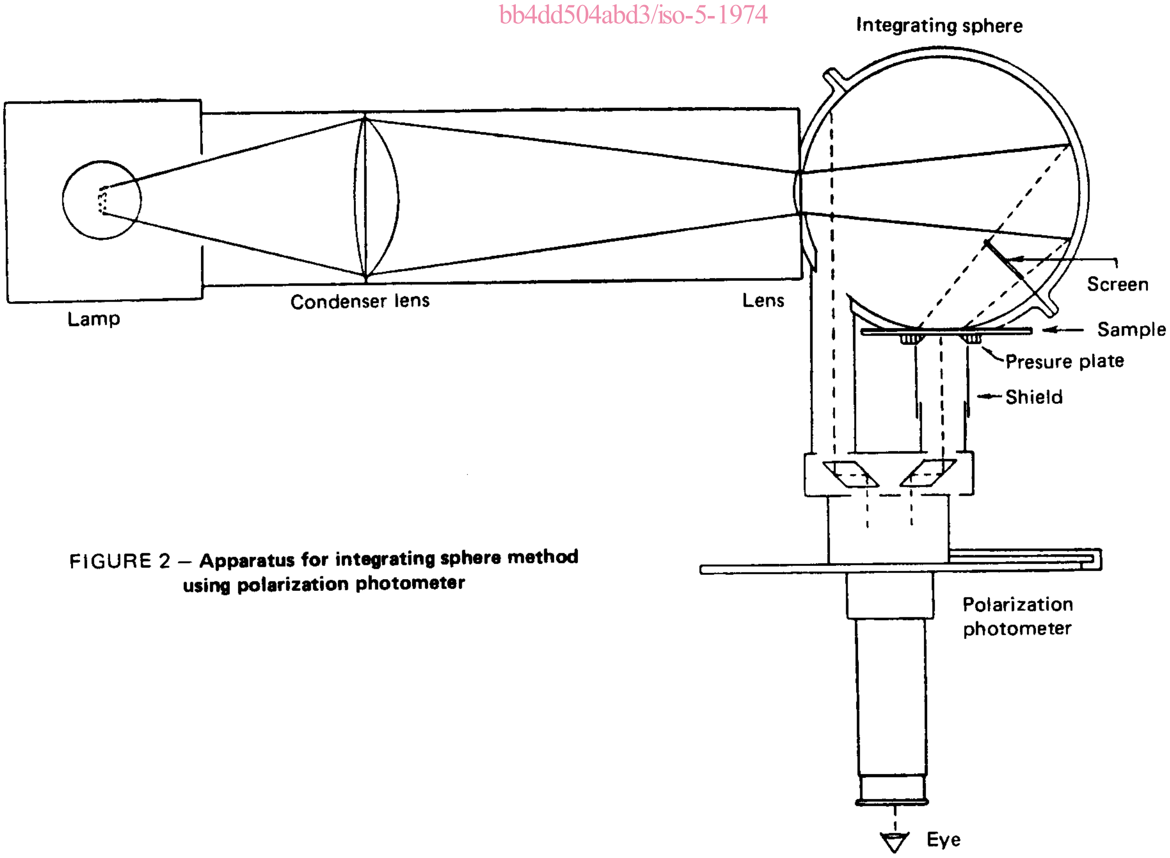

FIGURE 2 – **Apparatus for integrating sphere method using polarization photometer**

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

$$\frac{P_0}{P_t} = \frac{l_0^{\,2}}{l_s^{\,2}} \qquad \ldots (2)$$

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

$$D = D_a + \log\left(\frac{l_0'}{l_s'}\right)^2 \qquad \ldots (3)$$

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).