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Abstracts of CIE Publications prepared within Division 2

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CIE RESEARCH NOTE

SURVEY OF REFERENCE MATERIALS FOR TESTING THE PERFORMANCE OF SPECTROPHOTOMETERS AND COLORIMETERS*

Summary:

A list of reference materials for testing the performance of spectrophotometers and colorimeters is given. Particular attention is paid to materials for the measurement of regular transmittance and for regular (specular) and diffuse reflectance. Materials for the calibration of wavelength scales and the measurement of stray light are also included. No examples were found of reference materials for the measurement of diffuse transmittance. Information on type of materials, suppliers, sizes available and calibration details is supplied.

Aperçu des matières de référence pour l'examen de la qualité des spectrophotomètres et des colorimètres

Résumé:

Une liste de matériaux de référence pour le contrôle de la performance de spectrophotomètres et de colorimètres est donnée. Une attention particulière est accordée aux matériaux de référence servant au mesurage du facteur de transmission régulière et du facteur de réflexion régulière et diffuse. Sont également compris des matériaux servant à l'étalonnage d'échelles d'indication de longueurs d'ondes et au mesurage de lumière parasite. Aucun exemple n'a été trouvé des matériaux de référence pour le mesurage du facteur de transmission diffuse. Des renseignements sont donnés sur des types de matériaux, des fournisseurs, des grandeurs proposées et des procédures d'étalonnage.

Überblick von Referenzmaterialien zur Prüfung der Güte von Spektralphotometern und Farbmessgeräten

Zusammenfassung:

Es wird eine Liste von Referenzmaterialien zum Prüfen der Leistungen von Spektrophotometern und Farbmessgeräten gegeben. Besondere Aufmerksamkeit wird Materialien zum Messen des Grades der

gerichteten Transmission und des Grades der gerichteten und gestreuten Reflexion gewidmet. Materialien für die Kalibrierung von Wellenlängenskalen und zum Messen von Streulicht sind auch berücksichtigt. Beispiele für Referenzmaterialien zum Messen des Grades der gestreuten Transmission wurden nicht gefunden. Informationen über die Arten der Materialien, die Lieferanten, die verfügbaren Größen und Einzelheiten der Kalibrierung sind angefügt.

1 Introduction

Spectrophotometry is the measurement of the ratio of two spectral radiometric quantities. Usually this means the measurement of the spectral transmittance or reflectance of material samples or of quantities derived from these. (The word spectrometry is preferred by many as the subject is not confined to the visible region as the syllables "photo" imply.) As the quantities measured are pure ratios there is no requirement for a fundamental physical standard as, for example, with length and time. However, the accuracy attained in any measurement depends critically on the design of the instrument and possibly on the quality of the sample itself. There are several sources of systematic error in spectrophotometers: the wavelength scale may be in error, the ratio scale may be non linear, the beam may not be strictly monochromatic, to list but a few [1]. There is thus a need for reference instruments in metrology laboratories in which all systematic sources of uncertainty have been carefully investigated. The primary scales thus realised can be made available to science and industry by means of calibrated material transfer standards or certified reference materials. These materials must be carefully selected so as to avoid sample related errors in the measurement process.

Instruments for use in colorimetry can be divided into two broad classes, spectrophotometers and tristimulus colorimeters. In the former case the data supplied with a transfer standard need only be in the form of measured spectral transmittance or reflectance for a defined geometry of illumination and view, but in the latter case other considerations apply. A colour specification [2], which consists of a set of three numbers for a given sample, is derived

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by integrating the measured spectrophotometric ratios with the CIE Colour Matching Functions which define the Standard Observer and the spectral power distribution of an illuminant, usually one of the CIE Standard Illuminants [3]. Nowadays the integration can be performed readily with a data system attached to the spectrophotometer. However, with a colorimeter it is necessary to simulate the illuminant with a practical source and the observer with a set of filtered detectors leading to direct measurements of colour specifications in some recommended system such as $x\ y\ Y$, CIELUV or CIELAB [2]. Since the simulations will never be perfect, colorimeters have more sources of systematic error than spectrophotometers from the point of view of absolute measurements (though not necessarily for colour-difference measurements). Reference materials for colorimetry require calibrations of spectral transmittance or reflectance where a spectrophotometer is to be used, and calibration of colour specification under a given standard illuminant where a colorimeter is to be used.

Transmittance is defined as the ratio of the transmitted radiant or luminous flux to the incident flux [4,5]. There are, however, two different kinds: regular transmittance (i.e., without diffusion) and diffuse transmittance. Total transmittance is the sum of both kinds. For many materials the boundary between regular and diffuse transmittance is not well defined and measured values may be a function of instrument geometry. The same considerations apply to reflectance, which is defined as the ratio of the reflected radiant flux to the incident flux [4,5]. For reflectance standards, examples of materials calibrated for regular (specular), diffuse and total reflectance are listed. One other quantity for which reference materials used in reflectance are frequently calibrated is

"radiance factor". This is defined [4,5] for a non-self-radiating body, in a given direction, as the ratio of the radiance of the body to that of the perfect reflecting or transmitting diffuser identically irradiated. Unlike reflectance, radiance factor is a directional quantity. It should be remembered that for diffusing materials the eye makes an assessment of radiance factor rather than reflectance.*

It is also necessary to state the geometries of the incident and collected beams of radiation. CIE Publication No.15.2 Colorimetry, [2] lists revised tolerances for diffusely reflecting samples together with tolerances for regular and diffusely transmitting samples, compared with those of the first edition (1970) of above document. But it must be stated that the tolerances which are appropriate for most colorimetric purposes are not necessarily adequate or appropriate for spectrophotometric measurements in general [6].

An ideal regularly transmitting sample would have no other effect than to attenuate the incident beam. In practice regularly transmitting samples always give a regularly reflected component which can in some instruments reach the detector by way of a second reflection [7,8]. There may be a small diffusely transmitted component of radiation and there may also be a deflection of the beam across a non-uniform detector. All these points must be carefully considered when selecting and designing reference materials for use as transfer standards but it should also be stressed that an instrument which is calibrated using near-ideal transfer standards is still prone to sample dependent errors. These can be direct or indirect. Consider the case of a sample with non-parallel faces. A direct error can arise from the sample not having a well-defined thickness. An indirect error can arise due to a deflection of the beam across a non-uniform detector. Thus, calibrated reference materials, although a major step in achieving greater accuracy of measurement, do not obviate the need for high-quality instruments and good quality control of samples.

Diffusely reflecting calibrated reference materials are used primarily as reference standards in colorimetry. Two types are in common use, those with a negligible regular (specular) component of reflectance and those with a glossy surface giving a well-defined regularly (specularly) reflected beam. Materials with a poorly defined regular component are not suitable as reflectance standards. The regularly reflected component is a source of systematic error on many instruments due to inadequacy of the gloss trap [9,10] but the advantage of glossy materials is that they do not adsorb dirt readily and can

* The CIE has also defined the term reflectance factor [4] as follows: reflectance factor (at a point of a surface, for the part of the reflected radiation in a given cone with apex at the point of the surface, and for incident radiation of given spectral composition and geometrical distribution): ratio of the radiant (luminous) flux reflected in the directions delimited by the cone to that reflected in the same directions by a perfect reflecting diffuser identically irradiated (illuminated). Some suppliers prefer to use the term reflectance factor rather than reflectance and radiance factor. However, for consistency with CIE Publication 15.2 (1986) reflectance and radiance factor are used throughout this report.

easily be cleaned. Reference materials with only a diffuse component of reflectance are frequently pressed powders intended for use over a limited period or blocks which can be scraped to reveal a fresh surface. Durable materials with only a diffuse component of reflectance can be made from white ceramics or opal glass. However, because of the problem of contamination by dirt with a rough surface, the stability of the reflectance should be checked periodically using either a glossy reference white or a fresh pressing of barium sulphate. The primary reference for colorimetry is now the perfect reflecting diffuser but in any practical colorimetric situation a white reference standard whose properties are known in terms of the perfect reflecting diffuser will be used [11-15].

A list of reference materials available on a commercial basis for testing the performance of spectrophotometers and colorimeters is presented. Primary consideration is given to the spectral quantities: regular transmittance, regular (specular) reflectance, diffuse reflectance, total reflectance and $0^\circ/45^\circ$ radiance factor together with their Helmholtz reciprocal geometries (i.e., with positions of source and detector interchanged). No suitable examples of reference materials for spectral diffuse or spectral total transmittance could be found.

2 List of Reference Materials for Testing the Performance of Spectrophotometers and Colorimeters

Note that where a wavelength range is given, this is the range for which samples can be purchased as individually calibrated items. The range of usefulness may be greater than this.

2.1 Regular Transmittance

- a) Neutral-density filters of Schott glass mounted in frames for 10 mm cuvette holders with transmittance values of 10%, 20%, 30%.
Supplier: NBS.
Calibrated at wavelengths of 440, 465, 546.1, 590, 635 nm; SRM 930D.
Alternatively a single filter of transmittance 30% and calibrated at 465 nm only may be supplied; SRM 2030 [16].
- b) Neutral-density filters of Schott glass in three sizes: 38mm diameter aperture in 51x51 mm holder, 25 mm diameter aperture in 51x28 mm holder and 30x8 mm aperture in a cuvette holder, with nominal transmittance values of 92%, 70%, 50%, 25%, 10%, 1% and 0.1%.
Supplier: Hire by NBS.

The filters are calibrated at a wavelength of 548.5 nm only [17].

- c) Neutral-density filters of Schott glass mounted in frames for 10 mm pathlength cuvette holders with transmittance values of 91%, 75%, 55%, 32%, 10%, 3.2%, 1%, 0.32% and 0.1%.

Suppliers: Pye Unicam, NPL.

The filters are available in boxed sets of nine or short sets of four with transmittance values of 55%, 10%, 3.2% and 0.1% from Pye Unicam calibrated for transmittance, traceable to NPL, for the wavelength 546.1 nm only, or as individual items from NPL calibrated at wavelengths of the customer's choice from 350 nm to 2300 nm [18]. The extension of the wavelength range to 4500 nm has recently been suggested [19].

- d) Metal on quartz filters, mounted in frames to fit 10 mm pathlength cuvette holders, with transmittance values of 10%, 30%, 90%.
Supplier: NBS.

The filters are made from two silica plates assembled by optical contact. With the 10% and 30% filters; one of the silica plates is coated with a partly transmitting thin film of chromium.

The transmittance of the filters is calibrated at each of the following ten wavelengths: 250, 280, 340, 360, 400, 465, 500, 546.1, 590 and 635 nm; SRM 2031 [20].

- e) Metal on fused silica neutral density filters mounted in frames to fit holders for 10 mm internal pathlength cuvettes. Transmittance values of 92%, 55%, 32%, 10%, 3.2% and 1% can be supplied.

Supplier: NPL.

The filters are available as individual items calibrated at wavelengths of the customer's choice from 200 nm to 2300 nm [8,18].

- f) Liquid filters made from a solution of cobalt and nickel salts in a mixture of nitric and perchloric acid. Three solutions of different concentrations are supplied in vials each containing 10 ml of solution. The absorbances are in the range 0.1 to 0.9; SRM 931b.

Supplier: NBS.

The absorbance of the solutions is calibrated at wavelengths of 302, 395, 512 and 678 nm. This material requires the use of the NBS standard cuvettes SRM 932.

- g) Solutions of nickel nitrate and cobalt nitrate.

Supplier: Laboratoires BIOTROL.

The filters are known as Holnicob and the set consists of three ampoules of nickel nitrate, three ampoules of cobalt nitrate and one of holmium nitrate. The first two materials are for calibration of the absorbance scales at wavelengths from 345 to 720 nm over the range 0.1 to 2.0 and the third for wavelength calibration over the range 345 to 640 nm [21].

- h) Crystalline potassium dichromate for use as an ultraviolet absorbance standard.

Supplier: NBS.

Absorbance is certified for five concentrations at wavelengths of 235, 257, 313, 345 and 350 nm; SRM 935 [22].

This material requires preparation of solutions of potassium dichromate in 0.001N perchloric acid.

This material also requires the use of the NBS standard cuvettes SRM 932.

2.2 Regular (Specular) Reflectance

- a) First-surface aluminium mirror on a glass substrate.

Supplier: NBS.

The mirrors are 51 mm in diameter and the reflectance is calibrated at 50 nm intervals from 250 nm to 900 nm, at 100 nm intervals from 900 nm to 1300 nm and at 250 nm intervals from 1500 nm to 2500 nm. In addition the mirrors are also calibrated at the laser wavelengths 632.8 nm and 1060 nm. Certified values of reflectance are for 6° angle of incidence but in addition non-certified values are also available for 30° and 45° angles of incidence; SRM 2003a.

- b) Second-surface aluminium mirror.

Supplier: NBS.

These mirrors are available in two sizes: 51 mm square, SRM 2023, and 25 mm x 102 mm, SRM 2024. The aluminium is deposited on a 2 mm thick fused-quartz plate. The mirrors are protected by a second similar plate attached to the first with epoxy cement. Calibrations are the same as for item a.

- c) Second-surface aluminium mirror with wedge.

Supplier: NBS.

This mirror has dimensions of 25 mm x 102 mm and the aluminium is deposited on the back surface of a 2 mm thick optical quality vitreous quartz plate with a wedge of 10 mrad (0.573°) between its long faces. The

mirror is protected by a second similar plate cemented to the first plate so that the front and back surfaces are parallel. Values of reflectance are certified for 6° angle of incidence on the first surface for the same wavelengths as item a; SRM 2025.

- d) First-surface gold mirror on a metallic substrate.

Supplier: NBS.

The mirrors are 51 mm in diameter and the reflectance is calibrated at 50 nm intervals from 600 to 1000 nm, at 100 nm intervals from 1000 nm to 1300 nm and at 250 nm intervals from 1500 nm to 2500 nm. The mirrors are also calibrated at the laser wavelengths 632.8 nm and 1060 nm. Certified values of reflectance are for 6° angle of incidence but in addition non-certified values are also available for 30° and 45° angle of incidence; SRM 2011.

2.3 Diffuse Reflectance

- a) Pressed barium sulphate powder

Specially purified barium sulphate is available from several manufacturers. An extensive review of the properties of barium sulphate pressings is contained in CIE Publication No.46 [13]. Clarke et al [23] give details of goniophotometric properties. The quality varies from one manufacturer to another and skill is needed in making pressings if reproducible values are to be obtained. Although barium sulphate pressings represent a good practical approximation to the perfect reflecting diffuser, their fragility precludes their use as calibrated transfer standards. Reflectances up to 2500 nm are quoted in the literature [24] but the infrared reflectance is shown to be a function of grain size.

Sources of supply include:

Eastman White Reflectance Standard.

Merck, Barium sulfat reinst, No.1750.

Hopkin and Williams (purified, but not to the highest grade).

Union Chimique Belge No.1184.

Wako Pure Chemical Industries, Japan.

VNIIM.

- b) Pressed polytetrafluorethylene (PTFE) powder*
Supplier: Allied Chemical Company.

* The following US patents are assigned to J A Seiner of PPG Industries, Inc. Pittsburgh, Pa: US Patent No 3764364, October 9 1973 and US Patent No 3956201, May 11 1976.

This material is marketed under the trade name of Halon. It was first proposed as a reference white to the CIE by Grum and Saltzman [25] and is being increasingly used as an alternative to barium sulphate. A full report of the properties has been given by Weidner and Hsia [26].

- c) Eastman White Reflectance Paint
Supplier: Eastman Kodak Company.

This material, which is a composition of barium sulphate, binder and solvent is intended primarily for use as an integrating sphere coating. Although not, strictly speaking, a standard reference material, it is included in this list because of its very widespread use. Erb [11] includes a survey of integrating sphere paints.

- d) Russian Opal
Supplier: Mashpriborintorg. Resale by NPL. Hire by NRC.

NPL has been fortunate to receive a supply of this material over the last twelve years, most of which is cut into 50 mm square samples approximately 10 mm thick which are then calibrated in the $0^\circ/45^\circ$, $0^\circ/\text{diffuse}$ or $8^\circ/\text{total}$ geometries. The wavelength range of calibration is usually 320 nm to 770 nm in 5 nm intervals but can be extended up to 2000 nm at intervals of 10 nm. Samples are also available from NRC on a hire-out basis. Russian opal combines high reflectance with durability, and fluorescence is not excited above 320 nm. The regular reflected component from the polished surface can be considered as a disadvantage. However, the cleanliness of a polished surface can be maintained whereas a matt surface picks up dirt much more readily and is difficult to clean. Also the machining of matt opal surfaces to give the same degree of roughness from sample to sample is an art that has yet to be fully realised.

- e) Ever-White

Supplier: Yoneda Glass Bead Mfg Co.
This is a recently developed opal, the neutrality and reflectance of this material being similar to Russian opal. Sizes of 40 mm square, 50 mm square and 32 mm diameter are routinely available but sizes up to 300 mm square can be supplied to special order. The material is usually supplied with representative data for spectral diffuse and total reflectance over the wavelength range 380 nm to 780 nm but samples can be individually calibrated on request in the $0^\circ/45^\circ$ geometry.

- f) White opal glass (Vitrolite)

Supplier: NBS.

This material is available in two sizes, 51 mm x 38 mm, SRM 2015, and 100 mm square, SRM 2016, certified for diffuse reflectance for both specular-included and specular-excluded geometries over the wavelength range 400 nm to 750 nm at 10 nm intervals. The total spectral reflectance of Vitrolite is a few per cent less than that of Russian opal or barium sulphate. Vitrolite is somewhat translucent [27,28].

- g) White ceramic tiles

Supplier: NPL.

These are available as a cheaper alternative to Russian opal and are produced as 102 mm or 152 mm squares. The spectral reflectance is a few per cent lower than for Russian opal or barium sulphate and the decrease of reflectance in the ultraviolet is more rapid. Calibrations are for the same geometries as for Russian opal but the lower wavelength limit is 350 nm.

- h) White ceramic tile

Supplier: NBS.

This material is available in two sizes: 51 mm square, SRM 2019, and 38 mm x 76 mm, SRM 2020. Values of total reflectance for 6° angle of incidence are certified for wavelengths of 250, 300, 350 nm and then at 10 nm intervals up to 2300 nm, 2400 nm and 2500 nm. Many additional non-certified values are also supplied in the form of reflectances at other wavelengths and different angles of incidence.

- i) White ceramic tile without glaze

Supplier: NIM.

The peak spectral reflectance of this material is claimed to be comparable to that of Russian opal although the decrease in the ultraviolet and infrared is more rapid. The preferred size is 52 mm diameter but samples up to 100 mm square can be supplied. Calibrations are for the $0^\circ/\text{diffuse}$ geometry at 10 nm intervals over the range 380 nm to 760 nm.

- j) Magnesium carbonate tablets

Supplier: LNE.

These tablets are made from magnesium carbonate powder compressed at a high pressure and are available in diameters of 50 mm and 60 mm. The material has a matt surface and can be cleaned by removing a fine layer of material with a sharp straight glass edge. Spectral radiance factor is

calibrated at 20 nm intervals from 400 to 800 nm.

k) Black glazed ceramic tile

Supplier: NPL.

These tiles, which are 102 mm square, are available calibrated in the same geometries and over the same wavelength ranges as Russian opal (item d). The diffuse reflectance of 1% has been chosen to give a small non-zero reading on colour-measuring instruments.

l) Black porcelain enamel

Supplier: NBS.

This material is available in two sizes: 51 mm square, SRM 2021, and 25 mm square, SRM 2022. Certification is over the same wavelength ranges as for the white ceramic tile, item h.

m) Ever Black

Supplier: Yoneda Glass Bead Mfg Co.

This is a highly polished vitreous material with a remarkably low diffuse reflectance (about 0.03%). Samples are routinely supplied in 40 mm square and 50 mm square sizes.

n) Ceramic colour standards

Suppliers: BCRA, NPL.

These tiles of area 102 mm x 102 mm are sold in sets of twelve. Two series have been manufactured, the first comprising nine chromatically coloured tiles and three greys and the second set comprising seven chromatically coloured tiles, three grey tiles plus a grey and a green colour difference tiles, the latter two having a small controlled colour difference from corresponding tiles in the same set. Calibrated tiles are supplied by NPL for the 0°/45°, 0°/diffuse and 8°/total geometries over the wavelength range 320 nm to 780 nm. Uncalibrated tiles but with NPL master data are supplied by BCRA [29-31].

o) Enamel colour standards

Supplier: OMH.

These materials consist of a glass-enamel surface on an iron plate of 72 mm diameter. There are sixteen samples in the sets, fourteen colour plates, one white and one dark grey. Calibrated samples are supplied for the 0°/45°, 0°/diffuse and 8°/total geometries at 10 nm intervals over the wavelength range 380 nm to 760 nm [32].

p) Gloss paint on cardboard samples calibrated for 45°/0° radiance factor

Supplier: BAM.

These materials are 100 mm square. There are nine colours in the set chosen to lie at central points of defined areas of the chromaticity diagram [33].

q) Retroreflective material on metal plates

Supplier: BAM.

These materials are 100 mm square. There are nine colours in the set chosen to lie at central points of defined areas of the chromaticity diagram [33,34].

r) Retroreflective material for coefficient of luminous intensity

Supplier: Hire by NBS.

These materials include two types of colourless retroreflectors - bead sheeting and prismatic or cube-corner reflector. There is a high-intensity specimen (encapsulated lens) and an engineering-grade specimen (enclosed lens) of bead sheeting. The prismatic or cube-corner reflector is of the two-orientation hexagon cube type of plastic retroreflector. These materials are for checking how well the geometrical parameters of the measurement system can be set. Also included are seven coloured filters plus a plastic ultraviolet-absorbing filter to check the spectral quality of the measurement system [35].

2.4 Wavelength-Calibration Standards

These are intended for use with spectrophotometers normally used in the regular transmittance mode.

a) Didymium glass wavelength standards

Supplier: NBS.

These filters are used for checking the wavelength scales of spectrophotometers between 400 and 760 nm. Two forms are available, a 10 mm x 30 mm sample supported in a holder which fits in the place of a standard analytical cuvette, SRM 2013, and a 51 mm square, SRM 2014 [36,37].

b) Holmium nitrate solution

Supplier: Laboratoires BIOTROL.

A solution of holmium nitrate is used to calibrate the wavelength scales of spectrophotometers in the range 350 to 680 nm.

2.5 Stray-Light Standard

Potassium iodide

Supplier: NBS.

This material is crystalline potassium iodide of established purity for use as a stray-light standard in the ultraviolet. Aqueous solutions made with this material are certified for their specific absorbance at 23.5°C over a wavelength range from 240 to 280 nm. An attenuator consisting of two 10% transmittance filters can be placed in the reference beam to increase the sensitivity of the test by a factor of 100; SRM 2033.

3 Conclusions

Reference materials should be recalibrated periodically by metrological laboratories. Geometrical tolerances for colorimetry have been published by the CIE for many years but it is important to remember that such tolerances cannot be assumed adequate for all spectrophotometric purposes.

No examples of reference materials for spectral diffuse transmittance have yet been noted. Finally it should be mentioned that there are known to be a number of materials in the development stage that have not been listed. Among these are BCR opal glass, BCR neutral-density filters, NBS holmium oxide filters for use as wavelength standards, coloured opal glasses in The Soviet Union and Japan, luminescent reference materials at BAM, and solutions for the measurement of regular transmittance by LNE.

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CIE RESEARCH NOTE

INTERNATIONAL INTERCOMPARISON ON TRANSMITTANCE MEASUREMENT
REPORT OF RESULTS AND CONCLUSIONS*Summary:*

Between 1978 and 1982, CIE TC 2-09 conducted an international intercomparison to assess the accuracy of transmittance measurements. Sixteen laboratories, including eleven national standardizing laboratories, took part in the intercomparison. Twelve sets of filters were used, each consisting of nine glass filters. The filters were selected so that the repeatability, linearity, wavelength accuracy, and stray light of the measurements could be characterized.

The analysis of the measurement data yielded the following results:

1. The measurement methods, repeatability, and accuracy of the participants varied greatly.
2. With one exception, the measurements of all laboratories were free of stray light.
3. The mean repeatability of the participants' equipment was $\bar{S}=0.00053$ t.u. (transmittance units, defined with a maximum value of 1) for nine laboratories, and $\bar{S}=0.00258$ t.u. for five laboratories that reported higher uncertainties.
4. The linearity was assessed with neutral filters. The results of seven laboratories agreed within 0.0004 t.u., and those of the remaining eight laboratories agreed within 0.0011-0.0029 t.u.
5. The wavelength error was $\Delta\lambda < 0.3$ nm for eleven laboratories, and $0.4 < \Delta\lambda < 1.0$ nm for four laboratories.
6. The three neutral filters were stable over four years. During the same time all the colour filters changed, and the changes differed from filter to filter and set to set. Therefore, the colour filters were suitable only for stray light tests.

Comparison internationale de mesures de facteurs de transmission

Compte rendu des résultats et conclusions

Résumé:

De 1978 à 1982, le TC 2-09 de la CIE a réalisé une comparaison internationale pour déterminer l'exactitude des mesures de facteurs de transmission. Seize laboratoires, dont onze laboratoires nationaux, ont pris part à cette comparaison. Douze jeux de filtres furent utilisés, chacun étant constitué de neuf filtres en verre. Les filtres furent choisis de manière à ce que la répétabilité, la linéarité, l'exactitude en longueur d'onde et la lumière parasite, lors des mesures, puissent être déterminées.

L'analyse des données des mesures a conduit aux résultats suivants:

1. La méthode de mesure, la répétabilité et l'exactitude varièrent énormément d'un participant à l'autre.
2. A une exception près, les mesures de tous les laboratoires furent exemptées de lumière parasite.
3. La répétabilité moyenne des équipements des participants fut de $\bar{S}=0.00053$ u.t. (Unité de transmission, définie avec une valeur maximale de 1) pour neuf laboratoires et de $\bar{S}=0.00258$ u.t. pour les cinq laboratoires qui donnèrent la plus grande incertitude.
4. La linéarité fut caractérisée au moyen des filtres neutres. Les résultats de sept laboratoires furent en accord à 0.0004 u.t., et ceux des huit laboratoires restants s'échelonnèrent entre 0.0011 et 0.0029 u.t.
5. L'erreur sur la longueur d'onde fut $\Delta\lambda < 0.3$ nm pour onze laboratoires et de $0.4 < \Delta\lambda < 1.0$ nm pour quatre laboratoires.
6. Les trois filtres neutres furent stables sur la période de quatre ans. Durant la même période tous les filtres colorés changèrent et les changements ne furent pas les mêmes d'un filtre à l'autre. Dans ces conditions, les filtres colorés ne furent utilisables que pour les tests de lumière parasite.

Internationale Vergleichsmessungen des Transmissionsgrades

Bericht über Resultate und Folgerungen

Zusammenfassung:

Zwischen 1978 und 1982 machte CIE TC 2-09 internationale Vergleichsmessungen, um die Genauigkeit von Messungen des Transmissionsgrades zu ermitteln. Sechzehn Laboratorien, darunter elf nationale Normal-Laboratorien, nahmen an den Vergleichsmessungen teil.

Zwölf Gruppen von Filtern wurden verwendet, von denen jede aus neun Glasfiltern bestand. Die Filter wurden so ausgewählt, daß die Wiederholbarkeit, die Linearität, die Wellenlängengenauigkeit und das Streulicht der Messungen charakterisiert werden konnte.

Die Analyse der Meßwerte führte zu den folgenden Ergebnissen:

1. Die Meßmethoden, die Wiederholbarkeit und die Genauigkeit der Teilnehmer variierte stark.
2. Mit einer Ausnahme waren die Messungen aller Laboratorien frei von Streulicht.

3. Die mittlere Wiederholbarkeit der Meßeinrichtungen der Teilnehmer betrug $\bar{S}=0.00053$ t.u. (Einheiten des Transmissionsgrades, definiert für einen Maximalwert = 1) bei neun Laboratorien und $\bar{S}=0.00258$ t.u. bei fünf Laboratorien, die höhere Unsicherheiten angaben.
4. Die Linearität wurde mit Neutralfiltern ermittelt. Die Resultate von sieben Laboratorien stimmten innerhalb von 0.0004 t.u., und die der übrigen acht Laboratorien innerhalb von 0.0011 bis 0.0029 t.u. überein.
5. Der Wellenlängenfehler war $\Delta\lambda < 0.3$ nm bei elf Laboratorien und 0.4 nm $< \Delta\lambda < 1.0$ nm bei vier Laboratorien.
6. Die drei Neutralfilter waren über vier Jahre stabil. Während des gleichen Zeitraumes änderten sich alle Farbfilter und die Änderungen variierten von Filter zu Filter und von Gruppe zu Gruppe. Deshalb waren die Farbfilter nur für die Streulicht-Tests geeignet.

1 INTRODUCTION

The importance of spectral transmittance measurements is increasing all over the world. Numerous spectrophotometers of single or dual light beam are used, equipped with modern electronics. With the increase in number of these measurements there has developed a demand for the standardization of spectrophotometer scales in order that results of spectrophotometric measurements can be more precisely compared with each other.

*This CIE Research Note was prepared by TC 2-09, chairman L. Fillinger, and co-author G. Andor, c/o National Office of Measures, P.O. Box 19, H-1531 Budapest, Hungary, on behalf of CIE Division 2: Physical Measurement of Light and Radiation.

After the importance of standardization of the spectrophotometric scales had been realized, an international intercomparison on transmittance measurement was organized in the framework of CIE TC-2.3 "Materials" as a fact-finding investigation of this field between 1978 and 1982. Together with the organizer, the National Office of Measures, Hungary, sixteen laboratories, including eleven national metrological laboratories, took part in the intercomparison.

2 FILTER GLASSES USED IN THE INTERCOMPARISON AND THEIR CHARACTERISTICS

The filter sets used in the intercomparison consisted of nine glass filters. They were selected so that with their help we could characterize the linearity (filters Nos.1-4), wavelength accuracy (filters Nos.7-9) and stray light (filters Nos.5-8) of the measurements. Some of their characteristics can be found in Table 1. The dimensions of each filter glass were 12.5x40 mm. The material of the glasses was a product of Jenaer Glasswerk Schott und Gen. Initially, 14 sets of filters were prepared by the Hungarian Optical Works, Budapest. Of these, twelve met the

Table 1. Some characteristics of glass filters used in the international intercomparison.

Serial number	Colour	Type	Thickness mm
1	Neutral	NG 4	1.0
2	Neutral	NG 4	1.5
3	Neutral	NG 4	2.0
4	Neutral	KG 1	2.0
5	Blue	BG12	2.0
6	Green	VG 6	2.0
7	Yellow	GG14	2.0
8	Red	RG 1	2.0
9	Didymium	BG35	2.0

Table 2. Testing of uniformity. Uniformity of three specimens measured for the international intercomparison. The quantity, $T(0^\circ)$, is the transmittance with the electric vector of the incident radiation horizontal, and $\Delta T_R(0^\circ)$ is its standard error based on four measurements. The quantities x , y are the coordinates, with origin at the center of the filter, of the center of the light beam in millimeters as received when looking into the direction of incidence.

x, y		Filter No.605		Filter No.505		Filter No.305	
		$T(0^\circ)$	$\Delta T_R(0^\circ)$	$T(0^\circ)$	$\Delta T_R(0^\circ)$	$T(0^\circ)$	$\Delta T_R(0^\circ)$
$\lambda = 550\text{nm}$	+1 0	0.49188	0.000063	-	-	0.08445	0.000013
	-1 0	0.49178	0.000034	-	-	0.08442	0.000006
	0 0	0.49163	0.000072	-	-	0.08444	0.000016
$\lambda = 440\text{nm}$	+1 0	0.21068	0.000047	0.64912	0.000106	0.08024	0.000040
	-1 0	0.21055	0.000042	0.64903	0.000118	0.08023	0.000031
	0 0	0.21067	0.000026	0.64890	0.000045	0.08023	0.000023