



COMMISSION INTERNATIONALE DE L'ÉCLAIRAGE
INTERNATIONAL COMMISSION ON ILLUMINATION
INTERNATIONALE BELEUCHTUNGSKOMMISSION

THE SPECTRORADIOMETRIC MEASUREMENT OF LIGHT SOURCES

PUBLICATION CIE N° 63 (1984)
BUREAU CENTRAL DE LA CIE
52, BOULEVARD MALESHERBES 75008 PARIS — FRANCE

This report has been prepared by CIE Technical Committee 1.2, Photometry and Radiometry. It has been approved by the majority of the Technical Committee and is recommended for study and application. This report is not an Officially Agreed CIE Recommendation approved by the National Committees of the Member Countries of the CIE. It should be noted that any recommendations in this report are advisory and not mandatory. The latest CIE Proceedings or CIE Journal should be consulted regarding the current status of this report and possible subsequent amendments.

Ce rapport a été préparé par le Comité Technique 1.2, Photométrie et Radiométrie de la CIE. Il a été approuvé par la majorité du Comité Technique et il est recommandé pour étude et application. Ce rapport n'est pas une Recommandation officielle de la CIE, approuvée par les Comités Nationaux des Pays Membres de la CIE. Il doit être noté que toute recommandation y figurant est donnée à titre de conseil et non d'obligation. En ce qui concerne la situation présente de ce Rapport et d'éventuelles modifications, il faut consulter le plus récent Compte Rendu de Session ou Journal de la CIE.

Dieser Bericht wurde vom Technischen-Komitee 1.2, Photometrie und Strahlungsmessung der CIE. Er wurde durch die Mehrheit des Technischen Komitees gebilligt und wird zum Studium and zur Anwendung empfohlen. Dieser Bericht ist keine offiziell anerkannte CIE-Empfehlung, der die Nationalen Komitees der Mitgliedsländer der CIE zugestimmt haben. Es sei darauf hingewiesen, dass jede Empfehlung in diesen Bericht als Anleitung dient und nicht verbindlich ist. Was den gegenwärtigen Status dieses Berichtes und mögliche Nachfolge-Ausgaben angeht, ziehe man die neuesten CIE-Tagungsberichte oder das CIE-Journal zu Rate.

© CIE 1984

FOREWORD

This technical report has been prepared by CIE Technical Committee 1.2 Photometry and Radiometry as part of its working programme. The Members of the Committee and Consultants during the period of preparation (1973-1983) are listed below.

Chairman

C L SANDERS¹), F ROTTER²)

Members

W R BLEVIN
F ROTTER
L MORREN¹), M G VANDERMEERSCH²)
M DODOVA
C L SANDERS¹)
J KRTEL
V KOP
T TIMONEN
J BASTIE
S NÜNDEL
G BAUER¹), D HAHN²)
O C JONES³), J R MOORE⁴)
M POPPE
D PELLI⁵), G DEITCH⁶)
C GENTILE
M SUZUKI
M KOEDAM
B HISDAL
W STANIOCH
G ISPASQIU
C J KOK⁵), F HENGSTBERGER⁶)
A CORRONS
L LIEDQUIST
P BLASER
J J RENNILSON
V E KARTASHEVSKAYA⁵), M MATVEEV⁶)
N PETROVIC

Australia
Austria
Belgium
Bulgaria
Canada
Czechoslovakia
Denmark
Finland
France
German Democratic Republic
Germany, Federal Republic
Great Britain
Hungary
Israel
Italy
Japan
Netherlands
Norway
Poland
Rumania
South Africa
Spain
Sweden
Switzerland
USA
USSR
Yugoslavia

Consultants

W BUDDE
J BONHOURE
J KROCHMANN
E J GILLHAM, M B HALSTEAD
J SCHANDA
J J de GROOT
F WATSON, E F ZALEWSKI

Canada
France
Germany
Great Britain
Hungary
Netherlands
USA

¹) up to 1979
²) from 1980

³) up to 1980
⁴) from 1981

⁵) up to 1981
⁶) from 1982

SUMMARY

The CIE, and other organisations, have in the past organised international comparisons of measurements of the spectral power distribution of various light sources, including fluorescent tubes. In these investigations some unexpectedly large differences were found between the results reported by different laboratories.

It was the consensus of the members of the CIE TC-1.2 Committee that before further large scale international comparisons of measurements were organised, a method (or a few basic methods) should be agreed upon that could result in better accuracy and hence closer agreement between the measurements of the participating laboratories and that could also serve as a guide for anyone wishing to set up new spectroradiometric laboratories.

The present report summarizes the opinions on this subject of the members of a Subcommittee who answered a questionnaire sent out by the Chairman of TC-1.2. It is designed primarily to assist workers in industrial standards laboratories, although it is not intended for use as a textbook. Its contents should not be interpreted so as in any way to inhibit research into new and improved methods of spectroradiometry.

This Technical Report is divided into two parts, the first of which covers in a general way the use of a spectroradiometer in measuring the spectral power distribution of any type of source, with particular reference to the determination of photometric and colorimetric properties. The second part relates to the measurement of various lamp types, particularly tubular fluorescent lamps. It is envisaged that further parts could be added, if required, to extend the coverage of the document to other types of source.

RÉSUMÉ

La CIE, ainsi que d'autres organisations, ont organisé au cours des années passées des comparaisons internationales portant sur la répartition énergétique spectrale de diverses sources lumineuses, dont des tubes fluorescents. Lors de ces études, des écarts importants et inattendus sont apparus entre les résultats des différents laboratoires.

Il y eut alors unanimité au sein des membres du Comité TC-1.2 de la CIE pour que, avant l'organisation de nouvelles comparaisons internationales sur une plus large échelle, il soit convenu d'une méthode de mesure (ou quelques principes de base) conduisant à une plus grande exactitude, donc à un meilleur accord entre les résultats des laboratoires participants; cette méthode de mesure pourrait aussi servir de guide pour quiconque souhaiterait installer de nouveaux laboratoires de mesures spectroradiométriques.

Le présent rapport résume les points de vue sur ce sujet des membres du Sous-Comité qui ont répondu au questionnaire établi par le Président du TC-1.2. Ce rapport est essentiellement destiné à aider les chercheurs des laboratoires d'étalonnage industriels, sans qu'il puisse être utilisé comme un manuel. En aucun cas, la façon d'interpréter son contenu ne devrait avoir pour conséquence d'interdire la recherche de méthodes nouvelles et améliorées de spectroradiométrie.

Ce Rapport technique est divisé en deux parties. La première concerne, de façon générale, l'emploi d'un spectroradiomètre pour la mesure de la répartition énergétique spectrale d'un type quelconque de source lumineuse, avec une considération particulière pour la détermination des propriétés photométriques et colorimétriques. La deuxième partie concerne la mesure de divers types de lampes, en particulier les tubes fluorescents. On envisage d'ajouter plus tard en cas de besoin d'autres chapitres pour étendre le document à d'autres types de sources.

ZUSAMMENFASSUNG

Die CIE und andere Organisationen haben in der Vergangenheit internationale Vergleiche der Messungen der spektralen Strahlungsverteilung von verschiedenen Lichtquellen, einschliesslich von Fluoreszenzlampen durchgeführt. In diesen Untersuchungen wurden unerwartet grosse Differenzen zwischen den Werten gefunden, die die verschiedenen Laboratorien berichtet haben.

Die Mitglieder des CIE-Komitees TC-1.2 waren übereinstimmend der Meinung, dass keine weiteren internationalen Vergleichsmessungen grossen Umfanges organisiert werden sollten, solange nicht über eine oder mehrere grundlegende Methoden Übereinstimmung erzielt wäre, die eine bessere Genauigkeit ergeben und somit auch eine engere Übereinstimmung zwischen den Messungen der teilnehmenden Laboratorien.

Diese Methoden könnten auch als Leitfaden für jeden dienen, der beabsichtigt, neue spektroradiometrische Laboratorien zu errichten. Der vorliegende Bericht fasst die Meinungen derjenigen Subkomiteemitglieder zu diesem Gegenstand zusammen, die einen Fragebogen beantwortet haben, den der Vorsitzende von TC-1.2 ausgesendet hatte. Der Bericht ist in erster Linie dazu bestimmt, den in industriellen Messlaboratorien Tätigen zu nützen, obwohl er nicht als Lehrbuch gedacht ist. Sein Inhalt sollte nicht so verstanden werden, dass er in irgendeiner Weise Forschungen über neue und verbesserte Methoden der Spektroradiometrie behindern könnte.

Dieser technische Bericht besteht aus zwei Teilen, von denen der erste die Verwendung eines Spektroradiometers zur Messung der spektralen Strahlungsverteilung beliebiger Lichtquellen in allgemeiner Weise behandelt, mit besonderer Berücksichtigung der Bestimmung von photometrischen und farbmtrischen Eigenschaften. Der zweite Teil behandelt die Messung von verschiedenen Lampentypen, besonders von röhrenförmigen Leuchtstofflampen. Es ist vorgesehen, weitere Kapitel bei Bedarf später hinzuzufügen, um den Anwendungsbereich des Dokumentes auf andere Arten von Lichtquellen auszudehnen.

TABLE OF CONTENTS

INTRODUCTION	9
Purpose of the report	10
Terminology	10
PART 1 THE SPECTRORADIOMETER AND ITS METHOD OF USE	12
1.1. Basic elements of a spectroradiometric system	12
1.2. Measurement of spectral irradiance	12
1.3. Measurement of spectral radiance and total flux	14
1.4. Input optical arrangement	16
1.5. Characteristics of monochromators	20
1.6. Detector and measuring system	23
1.7. Standard sources	29
1.8. Methods of measurement	29
1.9. Error analysis	42
1.10. Accuracy requirements	44
APPENDIX 1A BASIC PRINCIPLES OF SPECTRORADIOMETRY	46
1A.1. Introduction	46
1A.2. Measurement of continuum radiation	47
1A.3. Measurement of line radiation	48
1A.4. Measurement of bandwidth	49
1A.5. Measurement of spectrum	50
1A.6. Experimental determination of $f(\lambda_s)$	52
PART 2 PROCEDURE FOR THE MEASUREMENT OF VARIOUS TYPES OF LAMP	55
2.1. Tungsten lamps	55
2.2. Tubular fluorescent lamps	58
REFERENCES	62
BIBLIOGRAPHY	64

INTRODUCTION

There are basically two approaches to the measurement of the photometric and colorimetric properties of sources:

- (i) Broad-band measurement, either with a detector, the spectral responsivity function of which is in accord with the CIE Standard Photometric Observer for photopic or scotopic vision, or with a tristimulus colorimeter whose spectral responsivity functions correspond to those of the CIE 1931 Colorimetric Observer or are a linear transformation of them. These methods will be referred to in this report as broad-band.
- (ii) Spectroradiometric measurement of the spectral power distribution of the light source.

It is difficult to adjust the relative spectral responsivity of detectors to match the CIE photometric and colorimetric observers, and in any case, for some other characteristics of light sources a knowledge of the spectral power distribution itself is needed at least in a relative form (e.g. for colour rendering index determination). When spectral measurements are directed towards the calculation of photometric quantities, the spectral power distribution has to be measured in such a way that an absolute value can be assigned to the integrated spectral characteristic.

In dealing with measurements of this type, it must be realized that if a spectroradiometric measurement is to give meaningful photometric and colorimetric results the measuring set-up, the individual components of the measuring system and the technique employed have to satisfy some quite stringent criteria.

The present report emphasises those elements of the spectroradiometric system and measurement technique that are important for the achievement of a result of acceptable accuracy. A paper on the measurement of spectral irradiance (Nonaka et al., 1972) was used as starting point in this work and the suggestions received from members of the Subcommittee on the Spectroradiometric Measurement of Light Sources were then added to the report - as far as the individual responses were not too contradictory to the consensus of the majority.

PURPOSE OF THE REPORT

- (i) To specify a simple but satisfactory procedure for the spectroradiometry of continuous, line and mixed sources of energy. The method applies to measurements of spectral irradiance, radiance and radiant flux in the near ultraviolet, visible and near infrared regions of the spectrum.
- (ii) To state procedures which should be used and also some which should not be used, and to provide in the latter case the reasons why they should not be used.
- (iii) To indicate the spectroradiometric accuracies required for specific different applications, including photometry, colour appearance and colour rendering.

The procedures given in this report cover the measurement of the spectral irradiance, radiance or radiant flux from a fluorescent lamp or part of a lamp, or from a fluorescent lamp plus a specified moderator, such as a luminaire. Other sources with a spectrum consisting of spectral lines or a combination of lines and a continuum are also considered.

TERMINOLOGY

The radiant quantities discussed in the present report are defined according to the 4th edition of the International Lighting Vocabulary (CIE 1983), but it may be helpful to repeat here the definitions of some of the more important concepts involved.

Irradiance (at a point of a surface) is defined as the quotient of the radiant flux incident on an element of the surface containing the point by the area of that element.

The symbol for irradiance is $E_e = d\phi_e/dA$ and the unit in the SI is $W.m^{-2}$.

Radiance, at a point on the surface of a source, in a given direction, is the quotient of the radiant flux per unit solid angle in the given direction of an element of the surface at this point, by the area of the orthogonal projection of this element on a plane perpendicular to this direction.

The symbol for radiance is $L_e = d^2\phi_e/(d\Omega.dA.\cos\theta)$ and the unit in the SI is $W.sr^{-1}.m^{-2}$.

The prefix "spectral" is an abbreviation for the complete expression "spectral concentration of", which is defined as the quotient of the radiometric quantity taken over an infinitesimal range on either side of a given wavelength, by the range.

For spectral irradiance, the symbol is $E_{e,\lambda} = dE_e/d\lambda$ and the unit in the SI is W.m^{-2} or $\text{W.m}^{-2}.\text{nm}^{-1}$.

For spectral radiance, the symbol is $L_{e,\lambda} = dL_e/d\lambda$ and the unit in the SI is $\text{W.sr}^{-1}.\text{m}^{-2}$ or $\text{W.sr}^{-1}.\text{m}^{-2}.\text{nm}^{-1}$.

In practice, the quantity measured will be the convolution of $E_{e,\lambda}$ or $L_{e,\lambda}$ with the spectral response function of the spectroradiometer system. Photometric quantities are derived from the spectral measurements by integrating a weighted function, such as $\int E_{e,\lambda} V(\lambda) d\lambda$. This integration is usually effected by summation over bands of width $\Delta\lambda$, ie $\sum E_{e,\lambda} V(\lambda) \Delta\lambda$. To obtain absolute values the sum must be multiplied by K_m , the luminous efficacy at the maximum of the $V(\lambda)$ function, defined as 683 lm.W^{-1} .

For a more detailed discussion of photometric quantities see CIE Publication 18/2, The Basis of Physical Photometry.

PART 1 THE SPECTRORADIOMETER AND ITS METHOD OF USE

1.1. BASIC ELEMENTS OF A SPECTRORADIOMETRIC SYSTEM

A spectroradiometric system is made up of three basic elements:

- (i) a source or sources, with power supplies and electrical measuring equipment,
- (ii) a monochromator, with optical coupling to the lamps and detector,
- (iii) a detector, with power supply, electronics for measuring detector output quantity and recording equipment.

Figure 1 shows a general diagram of the arrangement of a typical spectroradiometer system. An introduction to the basic principles of spectroradiometry appears as an appendix to this report.

An attempt will be made to indicate the limitations of various practical arrangements of spectroradiometers. Further parts may be added later to extend the scope of this report, expanding on particular aspects of measurement techniques.

1.2. MEASUREMENT OF SPECTRAL IRRADIANCE

Normally the measurement process involves the comparison of the test source with a standard source (usually a tungsten filament lamp) having a known spectral power distribution. In all cases, the exact conditions of calibration must be stated so that they can be reproduced when the source is operated on subsequent occasions.

In the case of irradiance, the quantity to be measured is the radiation from the source in a given direction reaching an area at a specified distance. When an absolute measurement is required, it is essential to define exactly the distance from the source to the plane of the irradiated surface. It is preferable to accept radiation from the whole of the source area, although with large sources a mask might be used to isolate a representative sample in order to prevent light entering the spectroradiometer at large off-axis angles.

The description of the set-up for an irradiance measurement should, therefore, always provide the following information:

- (i) The orientation in space of the lamp and details of the lampholder and housing (if any).
- (ii) The direction with respect to the lamp of the centre of the irradiated area and its distance from the lamp.

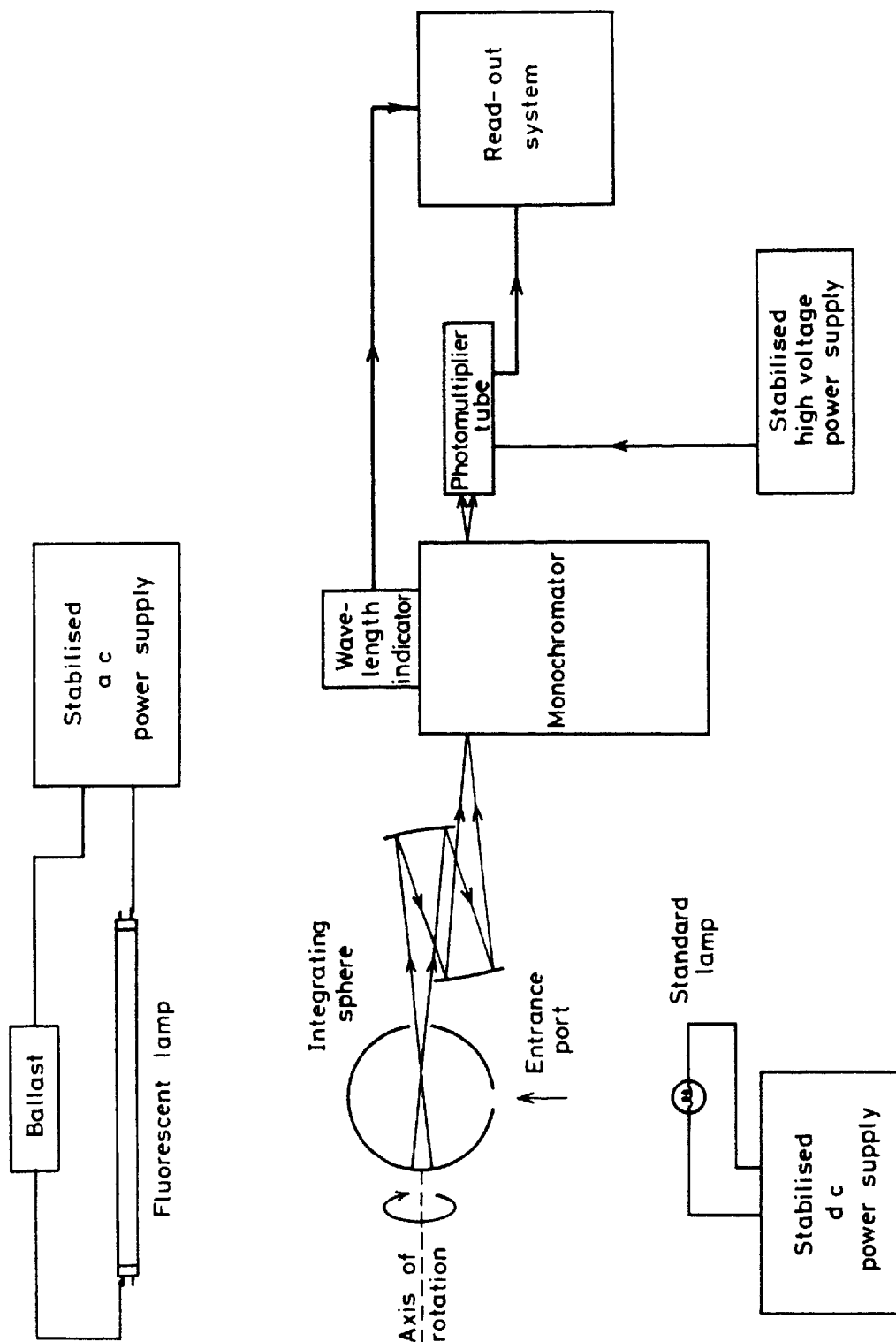


Figure 1. Schematic layout of a spectroradiometer system.

- (iii) The orientation and extent of the area to which the calibration applies.

In order to reduce errors due to the non-linearity of the measuring system the signals from the test source and the standard should be as nearly equal as possible. To this end the distances of the two sources may be adjusted appropriately. Where sources having dissimilar spectra as, for example, a fluorescent and a tungsten lamp are to be compared, then there are bound to be considerable, unavoidable differences in the signal levels in some regions of the spectrum and the demands on the linearity of the system are correspondingly greater.

1.3. MEASUREMENT OF SPECTRAL RADIANCE AND TOTAL FLUX

1.3.1. Spectral radiance

For a radiance measurement, it follows from the definition of the quantity that radiation emitted from a defined part of the source in a given direction is to be measured. Radiation will usually be accepted from only part of the radiant area of the source, the selected locality being isolated by imaging it on a suitable field stop. The care necessary in defining the specified area will depend on the spatial uniformity of the region under study. The preferred calibration technique involves the direct substitution of a spectral radiance standard for the test source; in this case the spectral selectivity and geometric properties of the optics used in defining the source area need not be known since they are common to each measurement.

Although a field stop is used to isolate a specific area of the source, diffraction effects in the optical system may allow the radiance of the surrounding areas to influence the radiance of the image. If the overall radiant areas of the standard and test sources outside the measurement area differ significantly in size or shape, then it may be necessary to apply a correction for this effect.

For a radiance calibration, a full description of the operating conditions should include the following information:

- (i) The orientation in space of the lamp or other type of source and details of the lampholder and housing (if any).
- (ii) The size and location of the calibrated area.
- (iii) The orientation of the principal axis and the acceptance angle of the imaging optics.

The most widely used standards of spectral radiance are tungsten ribbon lamps, but for lower radiance levels a surface of known spectral reflectance characteristics is sometimes employed, irradiated by a standard of spectral irradiance.

The signals from the test source and the standard should be made as nearly equal as possible in order to reduce the likelihood of errors arising due to any non-linearity in the measuring system. If a means of attenuation is used in front of the stronger source, then the attenuation factor must be known accurately at each wavelength.

Although industrial laboratories usually prefer to restrict themselves to comparisons made on a geometrically "like-with-like" basis, it may sometimes be necessary to measure spectral radiance by reference to a standard of spectral irradiance. In this case, the spectral radiant intensity of a known area of the test source (or its image) may be deduced from the spectral irradiance produced by it at a known distance. Spectral radiance is then obtained by dividing the spectral radiant intensity by the area of the mask. In such an intercomparison, a correction must always be made for the spectral transmittance of the imaging system and the geometrical conditions must be well defined and measured to the necessary accuracy. It is advisable to check the measurement by an independent experiment, for example one using broad-band rather than monochromatic radiation. (Bauer, 1973).

1.3.2. Geometrically total spectral radiant flux

For the measurement of geometrically total spectral radiant flux, the test source must be placed in an integrating sphere and light from the exit port of the sphere used to irradiate the input optics of the spectroradiometer. Internal screens must be provided, painted to match the walls of the sphere, to ensure that no part of the source is visible from the exit port.

For a measurement of total flux, it is important to specify which way up the lamp is operated.

A correction for the spectral selectivity of the integrating sphere and any auxiliary optics must be applied if the standard is of the directional type. If, however, a standard of geometrically total spectral radiant flux is available it may be substituted for the test source and the need for a sphere correction is then minimised, except for the effect of self-absorption in cases where it is not possible to have both sources in the sphere simultaneously. (CIE 1973).

Special precautions must be taken and additional corrections may be

required when the standard and the source to be measured have different spatial distributions of spectral radiant flux.

1.4. INPUT OPTICAL ARRANGEMENT

In the case of irradiance measurement direct irradiance of the entrance slit of the monochromator by the sources is best avoided because of the resultant variation in the irradiance distribution in the monochromator and also over the photocathode of the detector. The use of a transmitting diffuser in front of the slit is unlikely to solve the problem and cannot be recommended. The degree of diffusion produced varies with wavelength and is, in many cases, almost zero at the red end of the spectrum.

The most accurate methods of spectral irradiance measurement use an integrating sphere before the entrance slit of the monochromator (see Figure 2). An entrance aperture is located on the sphere wall at 90° to the optical axis of the monochromator. The sphere may conveniently be rotated about a diametrical axis coincident with the optical axis of the monochromator into the two symmetrical positions where the entrance aperture is in a vertical plane. In one position radiation from a standard source may enter the aperture, in the other radiation from the test source. Alternatively the sphere may be fixed in position and the sources moved so as to permit first one and then the other to irradiate the entrance port. It should be noted that perfect diffusion is not always essential, although it is important that radiation from both sources is treated in a similar manner. This condition is more difficult to satisfy when the sources to be compared differ markedly in size or shape. The directly irradiated area of the sphere wall should preferably be identical for the test and standard sources, but where this cannot be achieved, it will normally be sufficient to ensure that the area of the sphere surface seen by the monochromator does not overlap the areas directly irradiated by either source. That is, radiation should enter the monochromator only after undergoing two or more reflections. Care should be taken to ensure that excessive stray radiation is not introduced by over-filling the monochromator with radiation from the sphere. Adequate screening must be provided to prevent radiation from sources other than the one being measured entering the sphere.

Under the above conditions the interaction of the polarization of the monochromator with the polarization of the sources is minimised by the fairly complete depolarization of the light by the sphere. The entrance

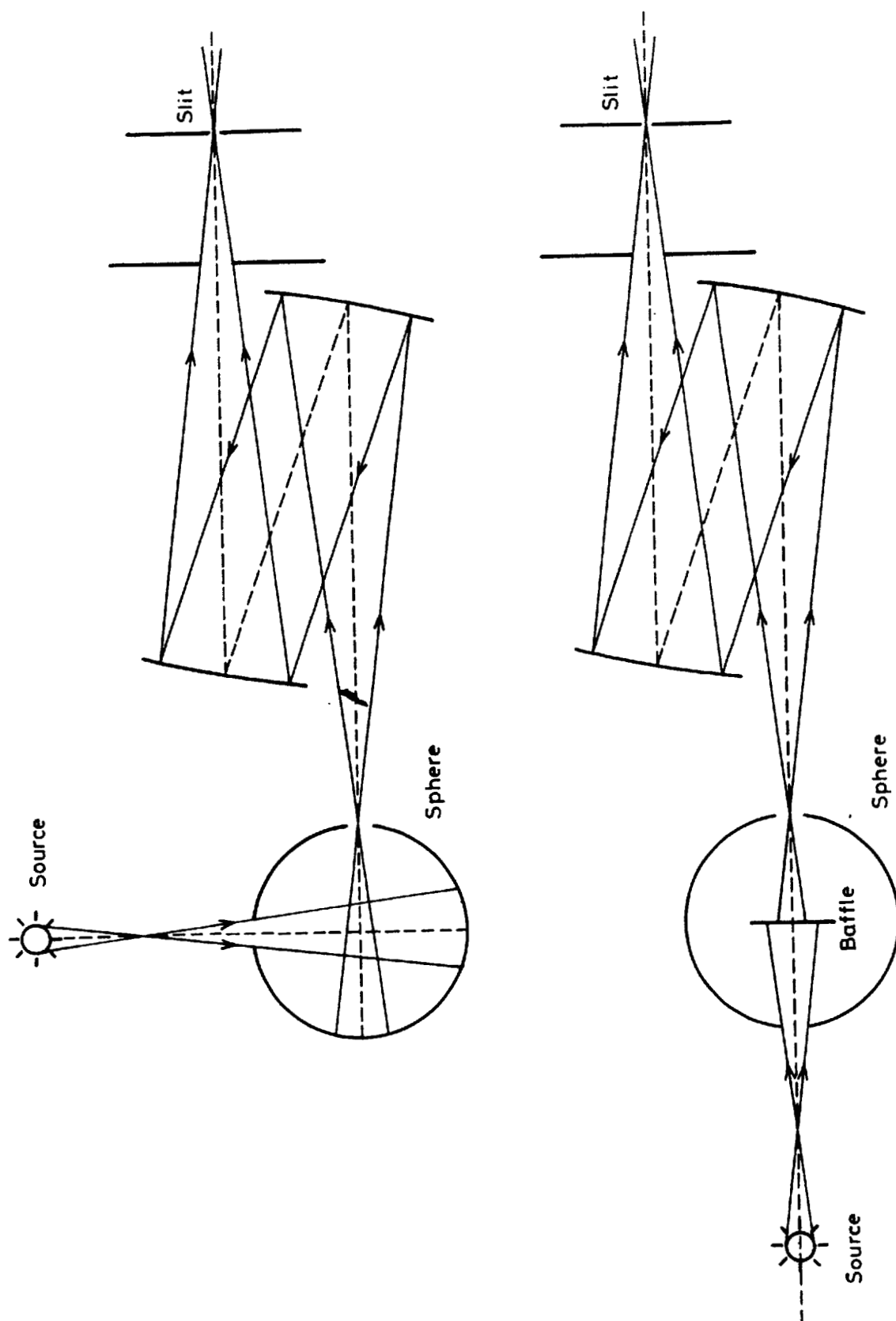


Figure 2. Alternative systems using an integrating sphere for the measurement of spectral irradiance

cone of the monochromator is completely and uniformly filled in each case. The fluxes from the standard and test sources are equally attenuated. The use of the sphere also provides great freedom in mounting the sources to be compared. The spectral irradiance in any other plane may be as easily measured by positioning the sphere with the entrance aperture in another orientation. The entrance aperture should have a sharp edge to avoid cosine errors. Sphere geometries used by Nonaka et al (1972) were: inner diameter 200 mm, entrance and exit port diameter 40 mm.

One disadvantage of using integrating spheres is the reduction in radiation reaching the detector due to absorption by the wall coating, particularly in the UV region. This may necessitate the use of simpler geometries.

A plane, reflecting diffuser irradiated normally and viewed at 45° (see Figure 3) may be used instead of the sphere at the risk of incurring somewhat larger systematic errors. The plane diffuser may be more efficient by a factor of 5 or 10, but it introduces larger polarization and angular sensitivity errors. A lens or mirror may be used to image it on the entrance slit in order to permit the diffuser to be farther from the monochromator and hence to give more space for mounting the sources. The plane diffuser should be considered where higher efficiency is required to reduce uncertainties caused by low signal to noise ratio.

Irradiation at 45° from normal has the disadvantage that a slight gradient of irradiation is produced on the diffuser, possibly causing differences of irradiation on the sensitive area of the detector. With prism instruments working in spectral regions where the prism material already shows some absorption, unequal irradiation might lead to increased errors. The symmetry of such an arrangement can be assessed by interchanging the test and standard sources.

For critical work, particularly when using a plane diffuser with 45° or perpendicular irradiation, the use of a reference source permanently irradiating one channel of the comparator may be preferred. The test source and the standard are then substituted in turn in the other channel, thus using each in exactly the same geometrical arrangement. The function of the reference source is to provide compensation for possible drifts in the response function of the spectroradiometer during the time required to compare the standard and test sources.

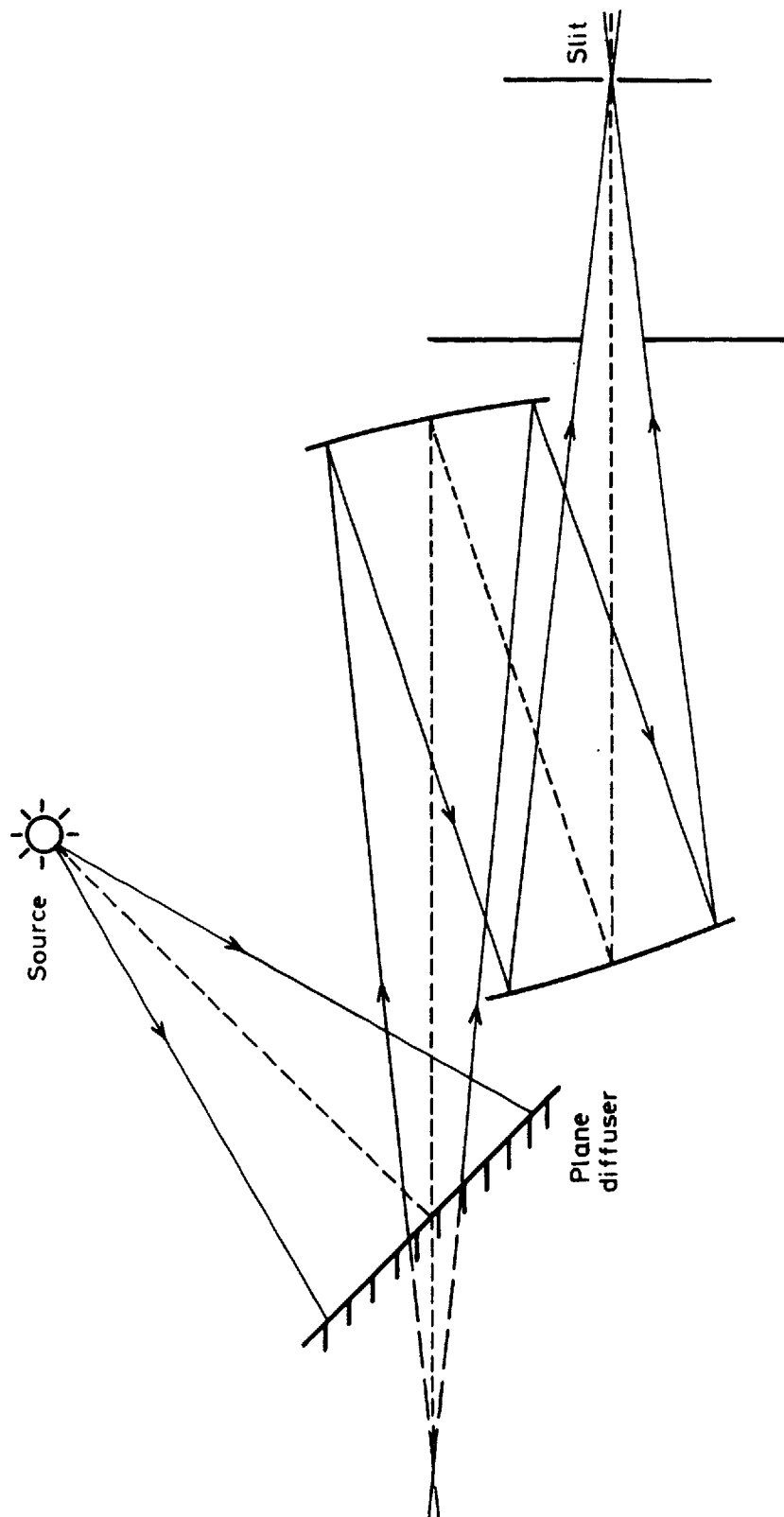


Figure 3. Use of a plane reflecting diffuser for the measurement of spectral irradiance

1.5. CHARACTERISTICS OF MONOCHROMATORS

The most important characteristics of a monochromator are its wavelength accuracy, effective bandwidth, light grasp and stray light performance.

The light grasp (etendu, throughput, efficiency) of a monochromator is the factor (Jacquinot, 1954) which determines, for a given bandwidth setting, the fraction of the radiant power incident at the plane of the entrance slit that eventually leaves the exit slit. The following expression may be useful as a figure of merit in comparing the performance of different monochromators in transmitting radiant power, when each instrument is adjusted to have the same bandpass:

$$\mathcal{T}(\lambda) = \frac{\tau(\lambda) \cdot h \cdot A}{f} \cdot \frac{d}{d\lambda}$$

$\tau(\lambda)$ is the spectral transmittance of the system, determined by the reflection and transmission losses, the efficiency of the diffraction grating, etc..

h is the height of the entrance and exit slits, assuming unit magnification.

A is the projected area of the limiting aperture, eg. the diffraction grating.

f is the focal length of the collimators.

$\frac{d}{d\lambda}$ is the angular dispersion of the monochromator.

In deducing the above expression it is assumed that the grating is operating in the Littrow mode (or the prism at minimum deviation) and that diffraction at slits and other apertures is negligible.

One of the disadvantages of a prism monochromator is that the bandwidth of the instrument varies with wavelength, being wider at longer wavelengths for a given slit setting. This is not the case with a grating monochromator since, for small angles of deviation, the dispersion of radiation by a grating is nearly constant. On the other hand, with a grating system, it may be necessary to use a filter or filters to eliminate second or higher order radiation, a problem which does not arise with prisms.

A double system, double prism, double grating or prism-grating is generally to be preferred for its superior stray radiation performance. Interferometric or holographic gratings appear to be better in this respect than their ruled equivalents. A prism-grating double