Reflectance changes in white reflectance standards measured in different instruments with 0/d geometry

J. Campos, A. Pons, J. Martín
Departamento de Metrología, Instituto de Física Aplicada, Consejo Superior de Investigaciones Científicas (CSIC)
28006-Madrid (SPAIN)
Corresponding author: A. Pons (apons@ifa.cetef.csic.es)

ABSTRACT

This work presents a comparison of reflectance measurements of different white reflectance standards, measured with three different spectrophotometers which include an integrating sphere accessory. The goodness of a procedure described elsewhere for the correct inclusion and exclusion of specular component of reflectance has been tested. Results obtained for the specular included geometry seem to probe the adopted procedure. Significant differences, not only for different angles of incidence but for the different sphere diameters, remain after correction for the specular excluded geometry.

1.- INTRODUCTION

Spectrophotometric errors in the measurement of reflectance 0/d have been widely studied by several authors, and procedures to minimise them have been published in the literature[1, 2, 3, 4, 5]. In all these studies, the calibration standard (usually a white standard) was assumed to be constant within its uncertainty, as it has to be for a standard, except for temporal drifts due to degradation of the reference surface produced by different causes. However, considering that 0/d reflectance measurement are done with an integrating sphere, it can be thought that the reflectance measured for a white standard may change from sphere to sphere, since they may be more or less close to an ideal integrating sphere and the incidence angle of the light may vary between 0º and 10º. Furthermore, in the case of reflectance measurements in the specular excluded geometry, the solid angle subtended by the exclusion port may change from instrument to instrument and an error arises in the measurement, since the angular distribution of reflectance is not the same for all standards. To correct for these effects a procedure was developed by J. F. Verrill at the National Physical Laboratory (NPL)[6]. This procedure consists of calculating spectral correction factors for the correct inclusion and exclusion of the specular component of reflectance and a formula to calculate the corrected reflectance value.

The aim of this work is to test the goodness of this procedure by measuring the reflectance of several types of white reflectance standard in three high quality spectrophotometers and compare the values obtained for every standard with every instrument, once the corrections have been applied.

2.- EXPERIMENTAL SETUP AND MEASUREMENTS

White standards used in this work are the most widely used for the calibration of spectrophotometers and colorimeters: glossy white ceramic tiles as well as matt ones, spectralon type white standards, BCR matt white standard as well as glossy ones. Spectrophotometers used have been a Lambda 900 and a Lambda 9 from Perkin Elmer, and a Cary 17 from Varian; all of them with the integrating sphere attachment to measure 0/d reflectance according to the CIE recommendations. The main differences among the instruments regarding the 0/d reflectance measurements are in the internal diameter of the sphere, in the paint covering the sphere and in the angle of incidence. The Lambda 900 has got a 150 mm internal diameter integrating sphere while the Lambda 9 and the Cary 17 have got a 60 mm internal diameter sphere. Both instruments from Perkim Elmer have got an integrating sphere covered by spectralon while the Cary 17 has got a barium sulphate paint. Finally, the incidence angle is 7º for the Perkin Elmer instruments for exclusion and inclusion of the specular component while in the case of the Cary 17 it is 0º when excluding the specular component and 7,5º when including it.

The correction factors for the measurement of reflectance 0/d (including and excluding the specular component) were determined for the three instruments as in ref. 7. Figure 1 and Figure 2 show the results obtained for the exclusion (K_2) and inclusion (K_3) of the specular component, respectively.

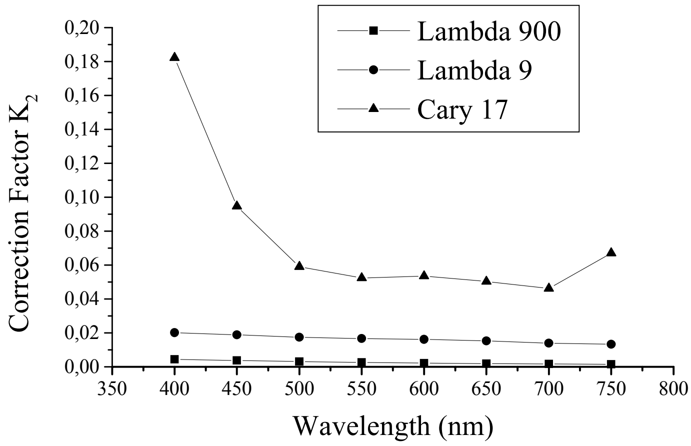


Figure 1: Spectral correction coefficient (K_2) of specular beam exclusion error obtained for the three spectrophotometers.

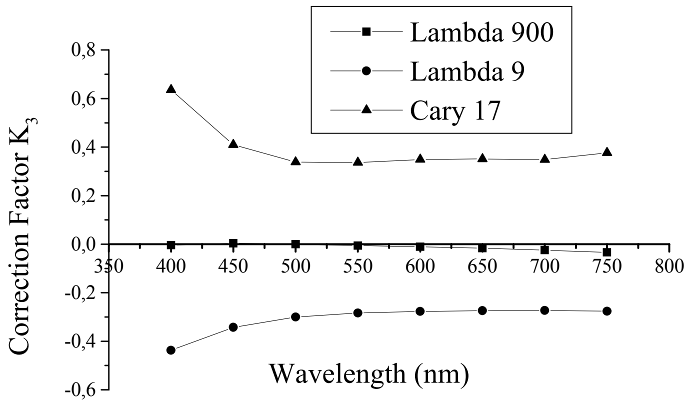


Figure 2: Spectral correction coefficient (K_3) of specular beam weighting error obtained for the three spectrophotometers

As it can be seen significant values, for both coefficients,, have been found in the case of the Cary 17; being also significant the correction coefficient K_3 in the case of Lambda 9. Afterwards, the reflectance of the standards was measured (including and excluding the specular component) in the three instruments taking one of the matt standards as a reference, the same for all instruments. The corrected reflectance value would be given by:

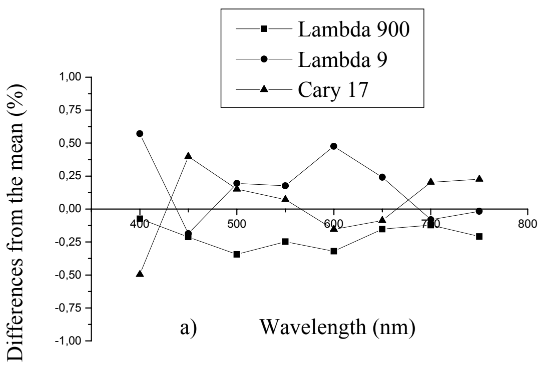
$$R(\lambda) = \frac{\rho_s(\lambda)}{\rho_t(\lambda)} R_t(\lambda) + K_i(\lambda)\left(\beta \frac{\rho_s(\lambda)}{\rho_t(\lambda)} - \alpha\right) \tag{1}$$

where ρ_s is the instrument's reading when the sample is measured, ρ_t is the reading when the reference is measured, R_t is the reference standard's reflectance and K_i is the correction coefficient for exclusion (i=2) or inclusion (i=3) of the specular component. Moreover α and β are coefficients related to the sample and the reference standard respectively, and whose values are one for glossy specimens and zero for matt ones. In practice, and because our purpose is to compare different instruments, relative corrected reflectance values (without consideration of the R_t value) instead of absolute ones have been used.

3.- RESULTS AND CONCLUSIONS

With the corrected reflectance values, we have compared the obtained values for every standard with every instrument. As an example in the following figures we have represented the differences (in percentage) from the mean value obtained with the three instruments, for three different situations. Figure 3 shows the differences for the ratio of corrected reflectance values of a glossy standard to one of the matt standards. Figure 4 shows the same situation but now for the ratio matt to matt standard. Finally figure 5 represents the differences found in the ratio of corrected reflectance values of a glossy standard to other of the glossy standards. In all cases results obtained for specular included geometry [section a) of the figures], as well as that for specular excluded geometry [section b) of the figures] are shown.

Accidental differences smaller than the typical measurement uncertainties have been found for the specular included measurements in all cases, which seems to conclude that in this geometry the adopted procedure allows to correct for the possible specular beam weighting error. However, a different situation can been observed if we consider the specular excluded geometry. Systematic differences larger than the typical measurement uncertainties have been found at least in two of the situations: glossy to matt and matt to matt, increasing these differences at shorter wavelengths. Significant differences can be observed not only for the different angles of incidence (Perkin Elmer spectrophotometers in comparison with Cary), but also for the different sphere diameters (see the differences between Lambda 900 and Lambda 9). In the first case, ratio of glossy to matt, the differences seem to indicate that the adopted procedure does not correct adequately for the posible specular beam exclusion error; but this assumption cannot be used to explain the differences in the matt to matt example. A different, and wavelength dependent, angular distribution of reflectance can be responsible for the different results obtained. A more exhaustive research is then proposed to explain the found differences.



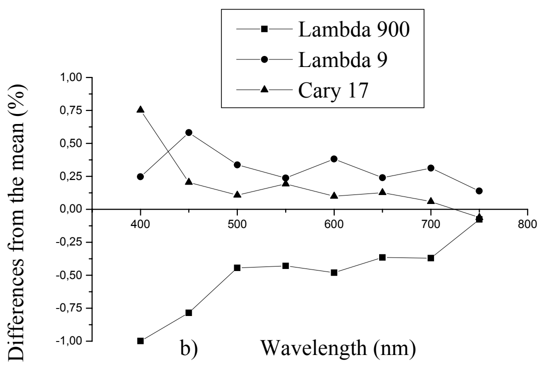


Figure 3: Differences in percentage, from the mean, as a function of wavelength for the ratio of glossy to matt standard. a) specular included geometry and b) specular excluded geometry.

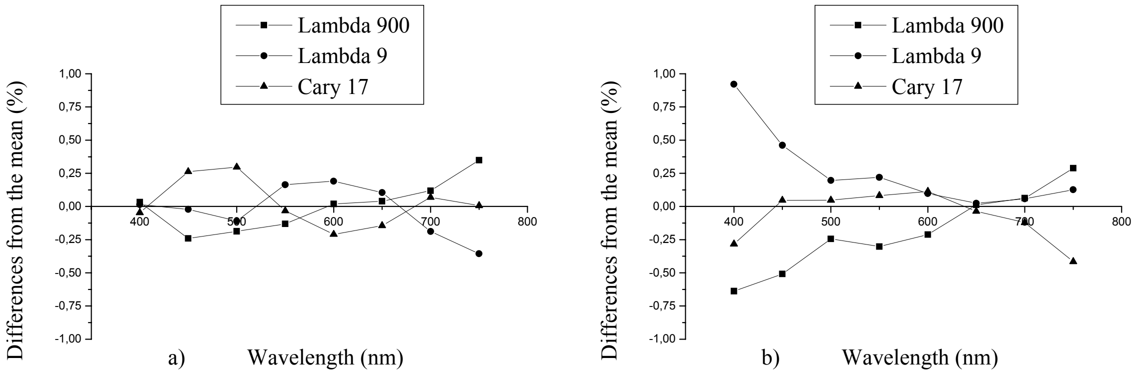


Figure 4: Differences in percentage, from the mean, as a function of wavelength for the ratio of matt to matt standard. a) specular included geometry and b) specular excluded geometry.

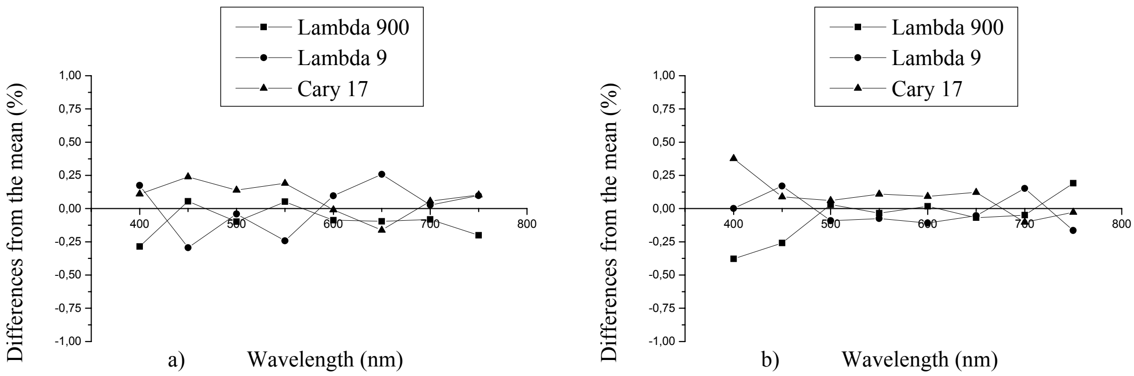


Figure 5: Differences in percentage, from the mean, as a function of wavelength for the ratio of glossy to glossy standard. a) specular included geometry and b) specular excluded geometry.

References

1. A. R. Robertson, "Colorimetric Significance of Spectrophotometric Errors", J. Opt. Soc. Am. 57, 691-698 (1967).
2. S. J. Kishner, "Effect of spectrophotometric errors on color difference", J. Opt. Soc. Am. 67, 772-778 (1977).
3. R. S. Berns and K. H. Petersen, "Empirical Modeling of Systematic Spectrophotometric Errors", Color Res. Appl 13, 243-256 (1988)
4. M. D. Fairchild and L. Reniff, "Propagation of Random Errors in Spectrophotometric Colorimetry", Color Res. Appl.16, 360-367 (1991).
5. R. S. Berns and L. Reniff, "An Abridged Technique to Diagnose Spectrophotometric Errors", Color Res. Appl 22, 51-60 (1997).
6. P.J. Clarke, A. R Hanson and J.F. Verrill, "Determination of colorimetric uncertainties in the spectrophotometric measurement of color", *Analytica Chimica Acta* **380,** 277-284 (1999).
7. J. Taylor, A.R. Hanson, P.J. Clarke, J. Campos, A. Pons, W. Czepluch, T. Jaaskelainen, J. Hiltunen, J. Gaudemer, O. Soares, J.L. Costa and L. Liedquist, "Good Practice Guide to Surface Colour Measurement", European Commission SMT4-CT96-2140 EUR 19552EN (2000).