INTERNATIONAL INTERCOMPARISON OF WAVELENGTH SCALE AND PHOTOMETRIC SCALE OF SPECTROPHOTOMETRY LABORATORIES CENAM - NRC - INMETRO - NIST

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Abstract

An intercomparison of the photometric scales and wavelength scales of four commercial spectrophotometers located at; CENAM, Querétaro.(México); NRC Ottawa (Canada), INMETRO Rio de Janeiro (Brasil) and NIST, Gaithersburg, MD. USA was realized in NORAMET and SIM was accomplished using a holmium oxide filters with wavelength range from aproximately 240 nm to 640 nm, Didymium glass and two set of neutral glass filters with nominal transmittances of 1% ,3%, 10%, 30%, 50% and 90 % over the wavelength range from 220 nm to 650 nm.
This comparison is very important for INMETRO, CENAM, NIST and NRC because it allows to give traceability and confidence in measurements results, the quality of the calibration services as well as estimating the errors, verify the results obtained by differents techniques of the sistems and instruments, and allows us to verify the difference among the results from the spectrophotometers of the laboratories than the total average and uncertainty.

Introduction

This document presents the intercomparison results of the photometric scale and the wavelength scale calibration of the spectrophotometers, these values are based on the use of Standards Reference Materials, illustrating the performance of the wavelength and photometric standards and how well four national standarizing laboratories agree using high quality samples. The Standards consists of a solution of holmium oxide in perchloric acid, holmium oxide glass filter and Didymium glass filter and neutral density filters.

This intercomparison of the spectrophotometry laboratories was made among the National Center of Metrology (CENAM), National Research Council (NRC), National Institute of Metrology (INMETRO) and National Institute of Standard and Technology (NIST). The VARIAN /CARY 5E is principal instrument used by CENAM and NIST in support the requests for photometric and wavelength scale measurements, while at INMETRO and NRC was used the Perkin Elmer/lambda 19, it is used as a primary standard transfer instrument. The spectral range of the VARIAN /CARY 5E spectrophotometers is from 175 nm to 3300 nm, and the Perkin Elmer/lambda 19 spectrophotometers is from 175 nm to 3200 nm. A features of these measurments in these kind of instruments is the spectral bandwidth parameter, which is user selectable in the Ultraviolet to visible spectral range. Additionally, These instruments have been characterized using absolute methods, to the wavelength scale: Physical constants such as spectral atomic emission, and to the Photometric Scale: Doble aperture method or reference beam attenuator.

The first measurements and results obtained in spectrophotometry laboratory of CENAM, NRC, INMETRO and NIST were done to study the so called " parameters of influence "whose direct effects and can cause variation in the measurements results. These instruments were previously characterized by the following experiments : Stray light, photometric noise, resolution, photometric stability, baseline and linearity to determinate the accuracy and reproducibility of photometric and wavelength scale.

Standards Identification

The three wavelength standards comprised: one holmium oxide glass, one didymium oxide glass and one holmium oxide in perchloric acid solution.

The photometric scale using NIST SRM 2031 metal on quartz filters and 1930, these SRM´s, are used for verification of the transmittance and absorbance scale of spectrophotometers in the ultraviolet and visible spectral regions.

Six neutral density filters and three wavelength standards were used for a comparision of regular spectral tranmittance measurements. The six neutral filters comprised: one set of three NIST SRM-1930 neutral glass filter (S/N 119), with nominal transmittances of 1 %, 3 % and 50% and one set of three NIST SRM-2031 neutral filter (S/N 365), two chromium-coated fused silica plates with nominal transmittances of 10 % and 30 % and one clear fused-silica plate with a nominal transmittance of 90%, and one empty filter holder. The calibration certificate included with this SRM warns that, on account of theirs reflective nature, these metal-on-quartz filters can generate reflection effects in the sample compartment of the spectrophotometer wich may degrade the accuracy of transmittance measurements.

The set of SRM-1930 neutral filters were to be calibrated for their regular transmittance factor over the spectral range 400 nm to 650 nm with a spectral bandpass of 1 nm. It was also requestd to report their regular transmittance factor at the following specified wavelengths and associated bandpass values (given in parentheses): 440 nm (2,2 nm), 465 nm (2,7 nm), 546.1 (6,5 nm), 590 nm (5,4 nm) and 635 nm (6,0 nm). The three filters were identified as 1-119, 3-119 and 50-119.

The set of SRM-2031 neutral filter (S/N 365) were to be calibrated for their regular spectral transmittance factor over the spectral range 220 nmto 650 nm a spectral bandpass of 1 nm. The three filters were identified as 365-10, 365-30 and 365-90.
The three wavelengths standards were calibrated for the wavelength of their transmittance minima over the wavelength range of 230 nm to 700 nm for the holmium oxide glass and solution filters, and over the range 400 nm 890 nm for the didymium oxide glass filters. All three wavelength standards were to be calibrated for spectral bandpass values of 1 nm, 2 nm and 3 nm.

Description of the Instrumentation

The spectrophotometers used in this intercomparison are characterized with estimates of systematic and statistical uncertanties. Their important feautres are given in table 1. The features are the same for each measurement systems (models: CARY/VARIAN 5E and PERKIN ELMER LAMBDA 19). For this reason the instrumental parameters and measurements perform were made under the same condition.

Uncertainty

The uncertainties, U_{lab} (Lab= CENAM, NRC, INMETRO and NIST) are the combination in quadrature of the uncertanties indicated in certificate of calibration of references materials $U_{cert.}$ and the statistical uncertainty expressed as two times the standard deviation of the mean.

Wavelength	Transmittance
$\boldsymbol{U}_{lab} = [(2\Delta\lambda)^2 + (U_{Lab.})^2]^{1/2}$ Error = $\lambda_t - \lambda_{\text{total average (All labs)}}$ Where: $\Delta\lambda_R = [\Sigma(\lambda_t - \lambda_{mean})^2/n(n-1)]^{1/2}$	$\boldsymbol{U}_{lab} = [(2\Delta T)^2 + (U_{Lab.})^2]^{1/2}$ Error = $T_t - T_{\text{total average (All labs)}}$ Where: $\Delta\lambda_R = [\Sigma(T_t - T_{mean})^2/n(n-1)]^{1/2}$

Here T_i and λ_i are the measured transmittance and wavelength, T_{mean} and λ_{mean} are the mean of the set of measurements and *n* is the number of measurements in the set.

General Characteristics of instruments

Table 1. Instrument general characteristics of CARY 5E from NIST - CENAM and Perkin Elmer lambda 19 from INMETRO - NRC.

Band pass	*Lamp*	*Grating*	*Monochromator System (nm)*	*Detection*
1nm,2 nm y 3 nm	Tungsten and Deuterium	Double grating	Double monochromator	Photomultiplier and Lead sulfide PbS

Results

The wavelength scale values were obtained at known wavelengths of the peak position of minimum transmittances and the accuracy was calculated considering fourteen wavelength in a spectral range from 230 nm to 850 nm. The results of the intercomparison are shown on tables from 1 to 9 from CENAM, NRC, INMETRO and NIST. The accuracy of wavelength scale of four instrument were evaluated with measurements of fourteen absorption bands were measured several times. The grant mean of wavelengths are listed on the tables 1,2,3,4,5,6,7,8 and 9.
The wavelength measurements were made as a function of spectral bandwidth and scan speed, these parameters are taken into account for the intercomparison CENAM, NRC, INMETRO and NIST laboratories, that provide data about the variability.

The photometric scale values were obtained at known wavelengths for different values of transmittances of filters, the results at specific ten wavelengths and at 1 nm bandpass are reported in tables from 10 to 15 on a scale from zero to unity (unity.corresponds to a transmittance factor of 100% relative to air).

Table 1. The uncertanties and Wavelength results of holmium oxide glass (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 1 nm.

λ_{CENAM} (nm)	λ_{NRC} (nm)	$\lambda_{INMETRO}$ (nm)	λ_{NIST} (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
241,581	*	241,472	241,6	0,100	*	0,207	0,2
279,331	279,14	279,304	279,4	0,100	0,08	0,201	0,2
287,622	287,5	287,552	287,6	0,108	0,1	0,200	0,2
333,908	333,99	333,858	333,9	0,105	0,08	0,201	0,20
347,867	347,91	347,852	*	0,184	0,13	0,235	*
360,942	360,96	360,868	360,9	0,097	0,08	0,199	0,20
381,725	381,65	381,608	*	0,110	0,1	0,199	*
385,899	385,93	385,882	*	0,176	0,08	0,219	*
418,799	418,69	418,77	418,8	0,135	0,08	0,221	0,20
424,984	424,95	425,006	*	0,111	0,09	0,233	*
445,692	445,57	445,644	*	0,099	0,08	0,199	*
453,626	453,47	453,624	453,7	0,097	0,08	0,200	0,20
460,197	460,04	460,14	460,2	0,133	0,08	0,218	0,20
484,308	484,17	484,322	*	0,125	0,09	0,207	*
536,384	536,4	536,456	536,433	0,125	0,09	0,203	0,22
637,584	637,67	637,624	637,8	0,145	0,17	0,241	0,20

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
241,55	-0,03	*	0,08	-0,05
279,29	-0,04	0,15	-0,01	-0,11
287,57	-0,05	0,07	0,02	-0,03
333,91	0,01	-0,08	0,06	0,01
347,88	0,01	-0,03	0,02	*
360,92	-0,02	-0,04	0,05	0,02
381,66	-0,06	0,01	0,05	*
385,90	0,00	-0,03	0,02	*
418,76	-0,03	0,07	-0,01	-0,04
424,98	0,00	0,03	-0,03	*
445,64	-0,06	0,07	-0,01	*
453,61	-0,02	0,13	-0,02	-0,09
460,14	-0,05	0,10	0,00	-0,06
484,27	-0,04	0,10	-0,06	*
536,42	0,03	0,02	-0,04	-0,02
637,67	0,09	0,00	0,05	-0,13

Table 2. The uncertanties and Wavelength results of holmium oxide glass (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 2 nm.

λ_{CENAM} (nm)	λ_{NRC} (nm)	$\lambda_{INMETRO}$ (nm)	λ_{NIST} (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
279,162	279,12	279,24	279,2	0,113	0,09	0,206	0,20
287,697	287,64	287,626	287,7	0,111	0,13	0,205	0,20
333,945	333,92	333,948	333,9	0,141	0,09	0,227	0,20
360,998	360,97	361,028	360,9	0,099	0,09	0,199	0,20
385,993	385,95	386,048	*	0,127	0,09	0,203	*
418,827	418,76	418,84	418,833	0,100	0,09	0,201	0,22
445,946	445,75	445,914	*	0,100	0,09	0,199	*
453,597	453,46	453,682	453,6	0,100	0,11	0,199	0,20
460,243	460,11	460,254	460,3	0,136	0,09	0,218	0,20
484,429	484,22	*	*	0,137	0,1	*	*
536,599	536,56	536,712	536,666	0,111	0,1	0,204	0,27
637,593	637,62	637,688	637,8	0,146	0,09	0,235	0,20

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
279,18	0,02	0,06	-0,06	-0,02
287,67	-0,03	0,03	0,04	-0,03
333,93	-0,02	0,01	-0,02	0,03
360,97	-0,02	0,00	-0,05	0,07
386,00	0,00	0,05	-0,05	*
418,82	-0,01	0,06	-0,02	-0,02
445,87	-0,08	0,12	-0,04	*
453,58	-0,01	0,12	-0,10	-0,02
460,23	-0,02	0,12	-0,03	-0,07
484,62	0,19	0,40	*	*
536,63	0,03	0,07	-0,08	-0,03
637,68	0,08	0,06	-0,01	-0,12

Table 3 The uncertanties and Wavelength results of holmium oxide glass (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 3 nm.

λ_{CENAM} (nm)	λ_{NRC} (nm)	$\lambda_{INMETRO}$ (nm)	λ_{NIST} (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
287,669	287,71	287,73	287,833	0,123	0,09	0,228	0,218
333,851	333,84	333,998	333,966	0,153	0,08	0,236	0,218
361,054	361	361,202	361,133	0,100	0,08	0,201	0,218
418,817	418,74	418,992	418,833	0,116	0,08	0,204	0,218
446,200	445,99	446,222	*	0,097	0,08	0,199	*
453,588	453,34	453,746	453,7	0,104	0,08	0,199	0,2
460,403	460,2	460,488	460,5	0,136	0,08	0,218	0,2
484,909	484,45	484,86	*	0,158	0,11	0,235	*
536,769	536,65	536,866	536,866	0,118	0,09	0,207	0,22
637,424	637,5	637,784	637,666	0,138	0,09	0,249	0,27

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
287,74	0,07	0,03	0,01	-0,10
333,91	0,06	0,07	-0,08	-0,05
361,10	0,04	0,10	-0,10	-0,04
418,85	0,03	0,11	-0,15	0,01
446,14	-0,06	0,15	-0,08	*
453,59	0,01	0,25	-0,15	-0,11
460,40	-0,01	0,20	-0,09	-0,10
484,74	-0,17	0,29	-0,12	*
536,79	0,02	0,14	-0,08	-0,08
637,59	0,17	0,09	-0,19	-0,07

Table 4. The uncertanties and Wavelength results of holmium oxide solution (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 1 nm.

λ_{CENAM} (nm)	λ_{NRC} (nm)	$\lambda_{INMETRO}$ (nm)	λ_{NIST} (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
287,200	287,16	287,122	*	0,097	0,08	0,199	*
333,507	333,33	333,466	*	0,104	0,09	0,204	*
345,467	345,26	345,396	*	0,097	0,08	0,201	*
361,346	361,13	361,274	*	0,102	0,08	0,199	*
385,707	385,64	385,598	*	0,136	0,09	0,218	*
416,360	416,29	416,234	*	0,136	0,08	0,218	*
451,467	451,3	451,426	*	0,118	0,15	0,250	*
467,880	467,95	467,808	*	0,134	0,08	0,217	*
473,560	473,4	473,556	*	0,136	0,09	0,230	*
485,267	485,15	485,234	*	0,097	0,08	0,199	*
536,627	536,56	536,546	*	0,104	0,08	0,199	*
640,533	640,52	640,506	*	0,097	0,08	0,199	*

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
287,16	-0,04	0,00	0,04	*
333,43	-0,07	0,10	-0,03	*
345,37	-0,09	0,11	-0,02	*
361,25	-0,10	0,12	-0,02	*
385,65	-0,06	0,01	0,05	*
416,29	-0,07	0,00	0,06	*
451,40	-0,07	0,10	-0,03	*
467,88	0,00	-0,07	0,07	*
473,51	-0,05	0,11	-0,05	*
485,22	-0,05	0,07	-0,02	*
536,58	-0,05	0,02	0,03	*
640,52	-0,01	0,00	0,01	*

Table 5. The uncertanties and Wavelength results of holmium oxide solution (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 2 nm.

λ_{CENAM} (nm)	λ_{NRC} (nm)	$\lambda_{INMETRO}$ (nm)	λ_{NIST} (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
287,289	287,21	287,240	*	0,104	0,08	0,199	*
333,533	333,33	333,547	*	0,131	0,08	0,219	*
345,422	345,3	345,463	*	0,125	0,09	0,217	*
361,200	361,09	361,200	*	0,119	0,08	0,202	*
385,933	385,79	385,843	*	0,097	0,08	0,203	*
416,689	416,51	416,643	*	0,104	0,08	0,200	*
451,333	451,2	451,317	*	0,097	0,08	0,199	*
467,955	467,97		*	0,137	0,08		*
473,511	473,36	473,533	*	0,104	0,09	0,208	*
485,333	485,13	485,310	*	0,097	0,08	0,199	*
536,933	536,84	536,907	*	0,097	0,08	0,199	*
640,867	640,75	640,763	*	0,097	0,08	0,201	*

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
287,25	-0,04	0,04	0,01	*
333,47	-0,06	0,14	-0,08	*
345,40	-0,03	0,09	-0,07	*
361,16	-0,04	0,07	-0,04	*
385,86	-0,08	0,07	0,01	*
416,61	-0,07	0,10	-0,03	*
451,28	-0,05	0,08	-0,03	*
467,96	0,01	-0,01		*
473,47	-0,04	0,11	-0,06	*
485,26	-0,08	0,13	-0,05	*
536,89	-0,04	0,05	-0,01	*
640,79	-0,07	0,04	0,03	*

Table 6. The uncertanties and Wavelength results of holmium oxide solution (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 3 nm.

λ_{CENAM} (nm)	λ_{NRC} (nm)	$\lambda_{INMETRO}$ (nm)	λ_{NIST} (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
286,955	287,05	287,027	*	0,105	0,08	0,199	*
333,422	333,29	333,540	*	0,167	0,08	0,219	*
345,555	345,41	345,707	*	0,105	0,08	0,209	*
361,222	361,09	361,283	*	0,105	0,08	0,201	*
386,022	385,95	386,107	*	0,105	0,08	0,213	*
417,000	416,81	417,033	*	0,097	0,08	0,199	*
451,400	451,18	451,437	*	0,097	0,08	0,201	*
473,600	473,47	473,730	*	0,119	0,08	0,206	*
485,311	485,09	485,360	*	0,104	0,08	0,202	*
537,289	537,15	537,317	*	0,104	0,08	0,199	*
641,267	641,09	641,203	*	0,097	0,08	0,211	*

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
287,01	0,06	-0,04	-0,02	*
333,42	0,00	0,13	-0,12	*
345,56	0,00	0,15	-0,15	*
361,20	-0,02	0,11	-0,08	*
386,03	0,00	0,08	-0,08	*
416,95	-0,05	0,14	-0,09	*
451,34	-0,06	0,16	-0,10	*
473,60	0,00	0,13	-0,13	*
485,25	-0,06	0,16	-0,11	*
537,25	-0,04	0,10	-0,07	*
641,19	-0,08	0,10	-0,02	*

Table 7. The uncertanties and Wavelength results of Didymium oxide glass (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 1 nm.

λ CENAM (nm)	λ NRC (nm)	λ INMETRO (nm)	λ NIST (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
431,398	431,28	431,380	431,40	0,106	0,08	0,223	0,20
440,610	440,5	440,568	440,70	0,146	0,08	0,209	0,20
472,823	472,71	472,808	472,77	0,151	0,1	0,238	0,22
481,329	481,09	481,312	481,30	0,132	0,08	0,217	0,20
513,659	513,57	513,672	513,69	0,107	0,08	0,260	0,20
529,290	529,2	529,304	529,37	0,101	0,08	0,210	0,22
573,067	573,13	573,232	573,20	0,120	0,16	0,276	0,2
684,700	684,85	684,804	684,80	0,177	0,12	0,272	0,2
739,972	740,39	740,428	739,70	0,608	0,18	0,390	0,2
807,474	807,74	807,598	806,20	0,142	0,13	0,232	0,20
879,514	878,78	880,756	*	0,597	0,16	0,497	*

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
431,36	-0,03	0,08	-0,02	-0,04
440,59	-0,02	0,09	0,03	-0,11
472,78	-0,05	0,07	-0,03	0,01
481,26	-0,07	0,17	-0,05	-0,04
513,65	-0,01	0,08	-0,02	-0,04
529,29	0,00	0,09	-0,01	-0,08
573,16	0,09	0,03	-0,07	-0,04
684,79	0,09	-0,06	-0,02	-0,01
740,12	0,15	-0,27	-0,31	0,42
807,25	-0,22	-0,49	-0,34	1,05
879,68	0,17	0,90	-1,07	*

Table 8. The uncertanties and Wavelength results of Didymium oxide glass (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 2 nm.

λ CENAM (nm)	λ NRC (nm)	λ INMETRO (nm)	λ NIST (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
431,800	431,64	431,800	431,83	0,145	0,09	0,163	0,22
440,747	440,59	440,730	440,77	0,155	0,11	0,142	0,22
472,646	472,61	472,706	472,73	0,151	0,07	0,179	0,22
480,986	480,93	481,156	481,03	0,162	0,07	0,151	0,22
513,708	513,65	513,774	513,80	0,190	0,08	0,209	0,20
529,369	529,29	529,492	529,47	0,106	0,07	0,143	0,22
573,459	573,42	573,512	573,47	0,103	0,07	0,212	0,22
684,739	684,84	684,892	684,87	0,241	0,08	0,225	0,22
740,158	740,4	740,234	740,23	0,153	0,16	0,329	0,22
807,504	807,76	807,718	806,03	0,101	0,09	0,172	0,22
879,710	879,02	880,604	*	0,548	0,39	0,463	*

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
431,77	-0,03	0,13	-0,03	-0,06
440,71	-0,04	0,12	-0,02	-0,06
472,67	0,03	0,06	-0,03	-0,06
481,03	0,04	0,10	-0,13	-0,01
513,73	0,02	0,08	-0,04	-0,07
529,40	0,04	0,11	-0,09	-0,06
573,46	0,01	0,04	-0,05	0,00
684,83	0,10	-0,01	-0,06	-0,03
740,26	0,10	-0,14	0,02	0,02
807,25	-0,25	-0,51	-0,46	1,22
879,78	0,07	0,76	-0,83	*

Table 9. The uncertanties and Wavelength results of Didymium oxide glass (CENAM, NRC, INMETRO and NIST) for espectral bandwidth of 3 nm.

λ_{CENAM} (nm)	λ_{NRC} (nm)	$\lambda_{INMETRO}$ (nm)	λ_{NIST} (nm)	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
440,806	440,69	440,920	441,07	0,132	0,08	0,237	0,27
472,421	472,45	472,816	472,63	0,153	0,08	0,256	0,21
480,633	480,65	480,984	481,00	0,107	0,08	0,225	0,23
513,757	513,77	514,020	513,97	0,190	0,08	0,253	0,21
529,496	529,43	529,756	529,77	0,122	0,08	0,229	0,21
573,998	573,69	573,998	574,13	0,115	0,08	0,281	0,21
684,837	684,82	685,066	684,97	0,263	0,08	0,284	0,21
740,354	740,46	740,592	740,43	0,169	0,15	0,271	0,21
807,513	807,81	807,874	806,20	0,118	0,08	0,243	0,20
879,837	878,82	880,832	*	0,428	0,19	0,465	*

Wavelength (nm) Total mean	CENAM Differences λ	NRC Differences λ	INMETRO Differences λ	NIST Differences λ
440,87	0,06	0,18	-0,05	-0,20
472,58	0,16	0,13	-0,24	-0,05
480,82	0,18	0,17	-0,17	-0,18
513,88	0,12	0,11	-0,14	-0,09
529,61	0,12	0,18	-0,14	-0,15
573,95	-0,04	0,26	-0,04	-0,18
684,91	0,07	0,09	-0,16	-0,06
740,46	0,11	0,00	-0,13	0,03
807,35	-0,16	-0,46	-0,52	1,15
879,83	-0,01	1,01	-1,00	*

Table 10. Photometric scale results of filter 2031-10

Wavelength (nm)	CENAM mean %T	NRC mean %T	INMETRO mean %T	NIST mean %T	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
2031-10								
250	9,9513	9,95	10,2528	9,9984	0,1003	0,18	0,1168	0,2761
280	9,6313	9,68	9,9269	9,7075	0,0904	0,09	0,1077	0,2912
340	9,3028	9,37	9,5141	9,3399	0,0901	0,08	0,1073	0,2802
360	9,4703	9,55	9,6813		0,0900	0,07	0,1073	
400	9,5332	9,58	9,7389	9,5804	0,0900	0,04	0,1077	0,2874
465	9,2597	9,29	9,441	9,2781	0,0900	0,04	0,1075	0,2783
500	9,5503	9,6	9,7373	9,5742	0,0900	0,05	0,1070	0,2872
546	10,4325	10,48	10,6352	10,426	0,1000	0,05	0,1157	0,3128
590	11,5022	11,54	11,7242	11,518	0,1100	0,08	0,1244	0,3455
635	12,5449	12,58	12,7578		0,1200	0,12	0,1334	

Wavelength (nm)	CENAM Differences %T	NRC Differences %T	INMETRO Differences %T	NIST Differences %T
2031-10				
250	0,0868	0,088	-0,2146	0,0397
280	0,1051	0,056	-0,1905	0,0289
340	0,0789	0,012	-0,1324	0,0417
360	0,0969	0,017	-0,1141	*
400	0,0749	0,028	-0,1308	0,0277
465	0,0575	0,027	-0,1238	0,0391
500	0,0652	0,015	-0,1218	0,0412
546	0,0612	0,014	-0,1416	0,0667
590	0,0690	0,031	-0,1530	0,0528
635	0,0827	0,048	-0,1302	*

Table 11: Photometric scale results of filter 2031-30

Wavelength (nm)	CENAM mean %T	NRC mean %T	INMETRO mean %T	NIST mean %T	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
2031-30								
250	29,5425	29,66	29,911	29,5672	0,2625	0,33	0,2722	0,1292
280	29,5258	29,69	29,9024	29,6254	0,2627	0,13	0,2787	0,0593
340	28,6127	28,62	28,8698	28,6049	0,2501	0,1	0,2612	0,0572
360	28,4852	28,51	28,719		0,2501	0,12	0,2609	
400	28,1592	28,2	28,3784	28,2213	0,2501	0,07	0,2610	0,0564
465	27,6936	27,71	27,8788	27,6884	0,2401	0,07	0,2514	0,0554
500	27,9515	27,95	28,127	27,8915	0,2501	0,09	0,2600	0,0558
546	28,8897	28,93	29,0738	28,826	0,2501	0,1	0,2607	0,0578
590	30,1280	30,15	30,2976	30,0688	0,2700	0,07	0,2807	0,0602
635	31,4154	31,48	31,5784		0,2801	0,09	0,2912	

Wavelength (nm)	CENAM Differences %T	NRC Differences %T	INMETRO Differences %T	NIST Differences %T
2031-30				
250	0,1277	0,010	-0,2408	0,1030
280	0,1601	-0,004	-0,2165	0,0605
340	0,0642	0,057	-0,1930	0,0719
360	0,0862	0,061	-0,1476	*
400	0,0805	0,040	-0,1387	0,0184
465	0,0491	0,033	-0,1361	0,0543
500	0,0285	0,030	-0,1470	0,0885
546	0,0402	0,000	-0,1439	0,1039
590	0,0331	0,011	-0,1365	0,0923
635	0,0758	0,011	-0,0871	*

Table 12. Photometric scale results of filter 2031-90

Wavelength (nm)	CENAM mean %T	NRC mean %T	INMETRO mean %T	NIST mean %T	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
2031-90								
250	90,8877	91,4	91,7016	91,3126	0,3918	0,69	0,3997	0,0430
280	91,3294	91,91	92,112	91,9665	0,3947	0,4	0,3914	0,1840
340	92,2291	92,55	92,6762	92,5545	0,3813	0,5	0,3899	0,1852
360	92,3417	92,71	92,7488		0,3807	0,22	0,3923	
400	92,4877	92,92	92,8682	92,8733	0,3804	0,31	0,3879	0,1858
465	92,6372	92,94	93,0024	92,7329	0,3804	0,32	0,3896	0,1855
500	92,7022	93,00	93,0368	92,9924	0,3804	0,44	0,3878	0,1860
546	92,7467	93,10	93,1024	92,7027	0,3806	0,38	0,3893	0,1855
590	92,7902	93,21	93,12	92,8204	0,3804	0,18	0,3907	0,1857
635	92,8219	93,15	93,132		0,3804	0,18	0,3876	*

Wavelength (nm)	CENAM Differences %T	NRC Differences %T	INMETRO Differences %T	NIST Differences %T
2031-90				
250	0,0438	0,057	-0,2448	0,1442
280	0,1338	0,042	-0,1604	-0,0149
340	0,0761	0,018	-0,1080	0,0137
360	0,0370	0,001	-0,0379	*
400	0,0872	-0,062	-0,0101	-0,0152
465	-0,0359	-0,036	-0,0987	0,1708
500	-0,0241	0,018	-0,0190	0,0254
546	-0,0695	-0,108	-0,1109	0,2888
590	-0,0866	-0,131	-0,0410	0,2586
635	-0,0215	0,002	0,0197	*

Table 13. Photometric scale results of filter 1930-1

Wavelength (nm)	CENAM mean %T	NRC mean %T	INMETRO mean %T	NIST mean %T	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
1930-1								
440	0,5609	0,556	0,5541	0,5586	0,0077	0,008	0,0584	0,0279
465	0,7875	0,783	0,7802	0,7890	0,0107	0,01	0,0589	0,0394
546	0,7155	0,718	0,7084	0,7154	0,0097	0,005	0,0588	0,0358
590	0,6637	0,67	0,6541	0,6643	0,0090	0,005	0,0586	0,0332
635	0,8876	0,891	0,8785	0,8870	0,0120	0,01	0,0592	0,0444

Wavelength (nm)	CENAM Differences %T	NRC Differences %T	INMETRO Differences %T	NIST Differences %T
1930-1				
440	-0,0035	0,001	0,0033	-0,0012
465	-0,0026	0,002	0,0047	-0,0040
546	-0,0011	-0,004	0,0059	-0,0011
590	-0,0007	-0,007	0,0089	-0,0012
635	-0,0015	-0,005	0,0075	-0,0010

Table 14. Photometric scale results of filter 1930-3

Wavelength (nm)	CENAM mean %T	NRC mean %T	INMETRO mean %T	NIST mean %T	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
1930-3								
440	2,2959	2,275	2,2925	2,2843	0,0289	0,02	0,0646	0,0685
465	3,0219	3,006	3,0218	3,0233	0,0376	0,013	0,0691	0,0907
546	2,8434	2,851	2,8445	2,8407	0,0355	0,023	0,0678	0,0852
590	2,6338	2,648	2,6341	2,6352	0,0331	0,013	0,0672	0,0791
635	3,2863	3,297	3,2806	3,2933	0,0410	0,018	0,0710	0,0988

Wavelength (nm)	CENAM Differences %T	NRC Differences %T	INMETRO Differences %T	NIST Differences %T
1930-3				
440	-0,0090	0,012	-0,0056	0,0027
465	-0,0036	0,012	-0,0035	-0,0051
546	0,0015	-0,006	0,0004	0,0042
590	0,0039	-0,010	0,0037	0,0026
635	0,0030	-0,008	0,0087	-0,0040

Table 15. Photometric scale results of filter 1930-50

Wavelength (nm)	CENAM mean %T	NRC mean %T	INMETRO mean %T	NIST mean %T	CENAM Expended Uncertainty	NRC Expended Uncertainty	INMETRO Expended Uncertainty	NIST Expended Uncertainty
1930-50								
440	49,8861	49,78	49,8792	49,5520	0,2399	0,34	0,2481	0,0991
465	53,2524	53,17	53,2348	53,2361	0,2563	0,27	0,2633	0,1065
546	52,6196	52,7	52,605	52,4294	0,2617	0,27	0,2690	0,1049
590	49,8535	49,97	49,8258	49,7601	0,2396	0,26	0,2479	0,0997
635	48,9282	49,07	48,8982	48,8237	0,2357	0,22	0,2429	0,0980

Wavelength (nm)	CENAM Differences %T	NRC Differences %T	INMETRO Differences %T	NIST Differences %T
1930-50				
440	-0,1118	-0,006	-0,1049	0,2223
465	-0,0291	0,053	-0,0115	-0,0128
546	-0,0311	-0,112	-0,0165	0,1591
590	-0,0011	-0,118	0,0265	0,0922
635	0,0018	-0,140	0,0318	0,1063

The average differences among the the readings of wavelengths scale and transmittances scale, the standard deviations and the estimated total uncertanties of this results at the 95% confidence level, are shown in the tables results and It observed that the were consistently smaller.
than combined uncertaty for the bandwidth dependence of these data was judged statistically insignificant, so that the average differences were taken to be representative of wavelength accuracy of the spectrophotometers. The dependence of these data was judged statistically insignificant, so that the average differences were taken to be representative of wavelength and transmittance accuracy of the spectrophotometers.

Hence, it is was concluded that the spectrophotometers requires no wavelength and photometric scale corrections. The differences plotted versus wavelength are show in the graphic 1-15 where may also be seen that in almost all cases the differeences among the uncertaties are smoller and are shown by the error bars in the graphics from CENAM, NRC INMETRO and NIST.

The graphics are from SRM 2031, 1930, Holmium (Glass and solution) and Didymium glass.

Considerations of graphics to the Photometric scale (neutral density filters).

1. The graphics indicate the dispersion values between percent of transmittance and wavelength.
2. The dotted line show the grant average (mean of mean of four laboratories)
3. The graphics include the uncertainty expanded that were gave for each laboratories, using K=2.

Considerations of graphics to the Wavelength scale (Didymium glass, holmium oxide solution and glass).

1. The graphics show the error versus wavelength
2. The errors were evaluated with differences between the grant mean of four laboratories and the values reported as mean of each lab.
3. The error bars at each point represent The expanded uncertainties.

The simbol (*) indicated that some values of NIST were not included at the graphics why the following reason :

- The transmittance values by NIST was not evaluated, at the wavelength 360 nm and 635 nm at neutral density filter 2031.
- Were not gave the wavelength values at 807 and 879, with SBW= 1,2 and 3
- Were not gave the values of holmium oxide solution
- Were not gave the wavelength values at 333, 381,385 and 484 with SBW= 1
- Were not gave the wavelength values at 347, 385, 445, 473 and 484 with SBW= 2
- Were not gave the wavelength values at 385, 445, 484 with SBW= 3

Conclusions

This intercomparison shows the state of spectrophotometer in the wavelength and photometric scale. The differences insignificant of the measurement between four labs indicate a good hability to determine the wavelength in four instrument. Since the disagreement among the four laboratories is small, the results of the intercomparison must be considered satisfactory.

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