



The Measurement of Color

Color Measurement and ISO/IEC 17025

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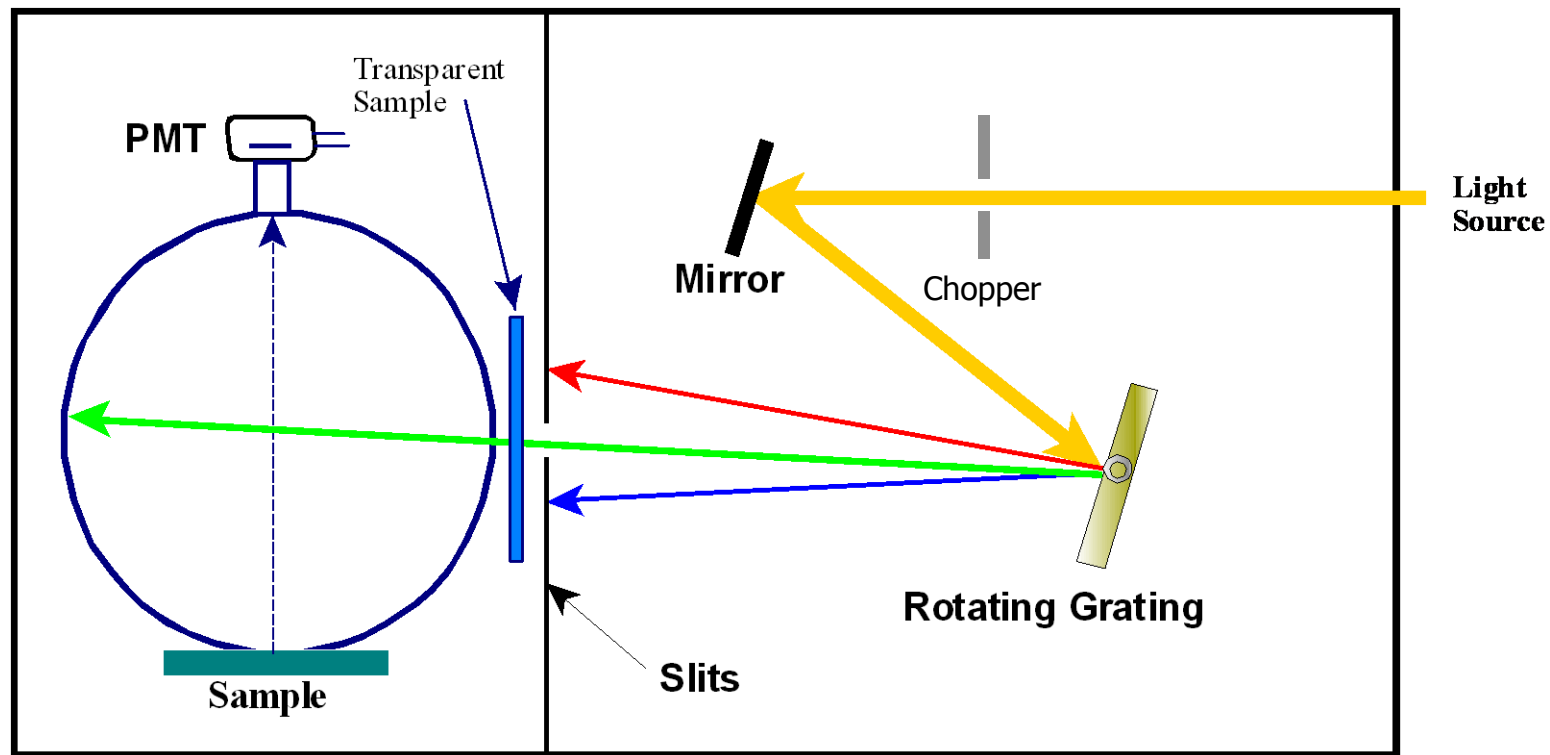
CORM
May 11, 2007



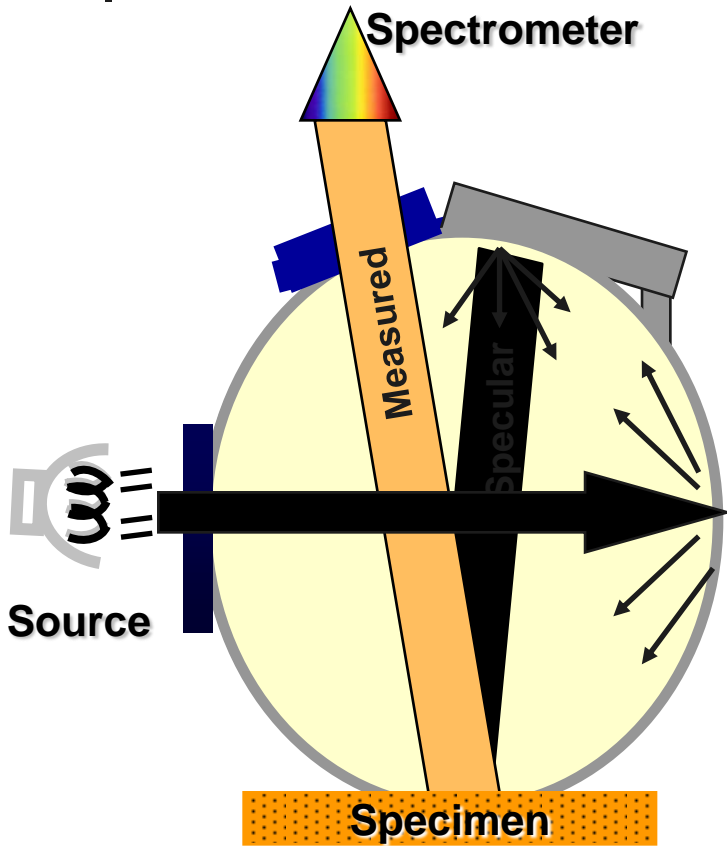
Light-Measuring Module Types

- Single-Grating Scanning Spectrophotometers
- CCD-, or Diode-Array Spectrophotometers (CMOS Arrays are becoming available)
- Multifilter Spectrometers

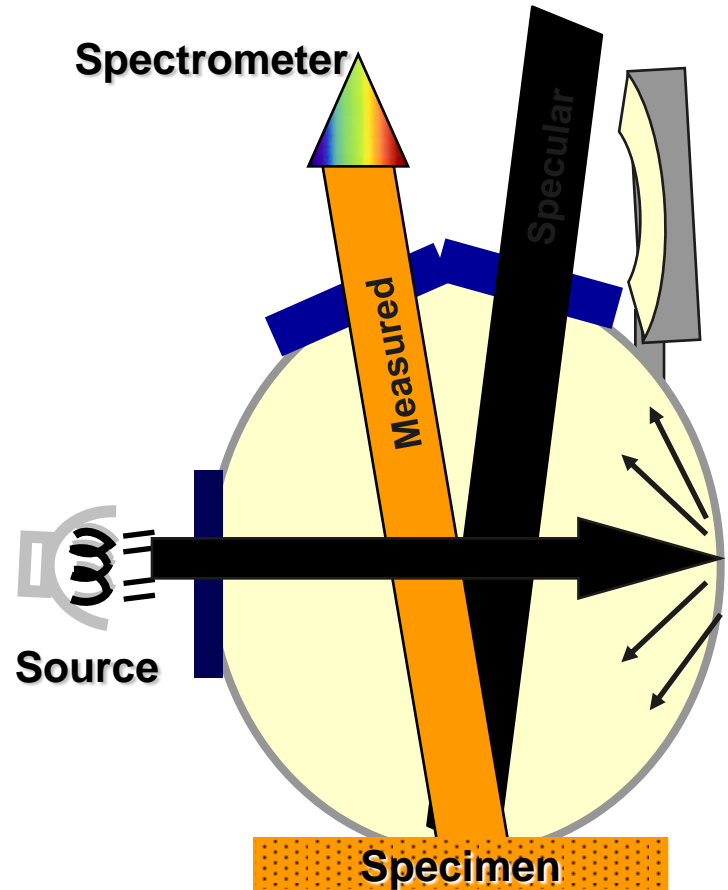
Schematic of a Single-Grating, Scanning Color Spectrometer



Sphere Geometry $d/8^\circ$

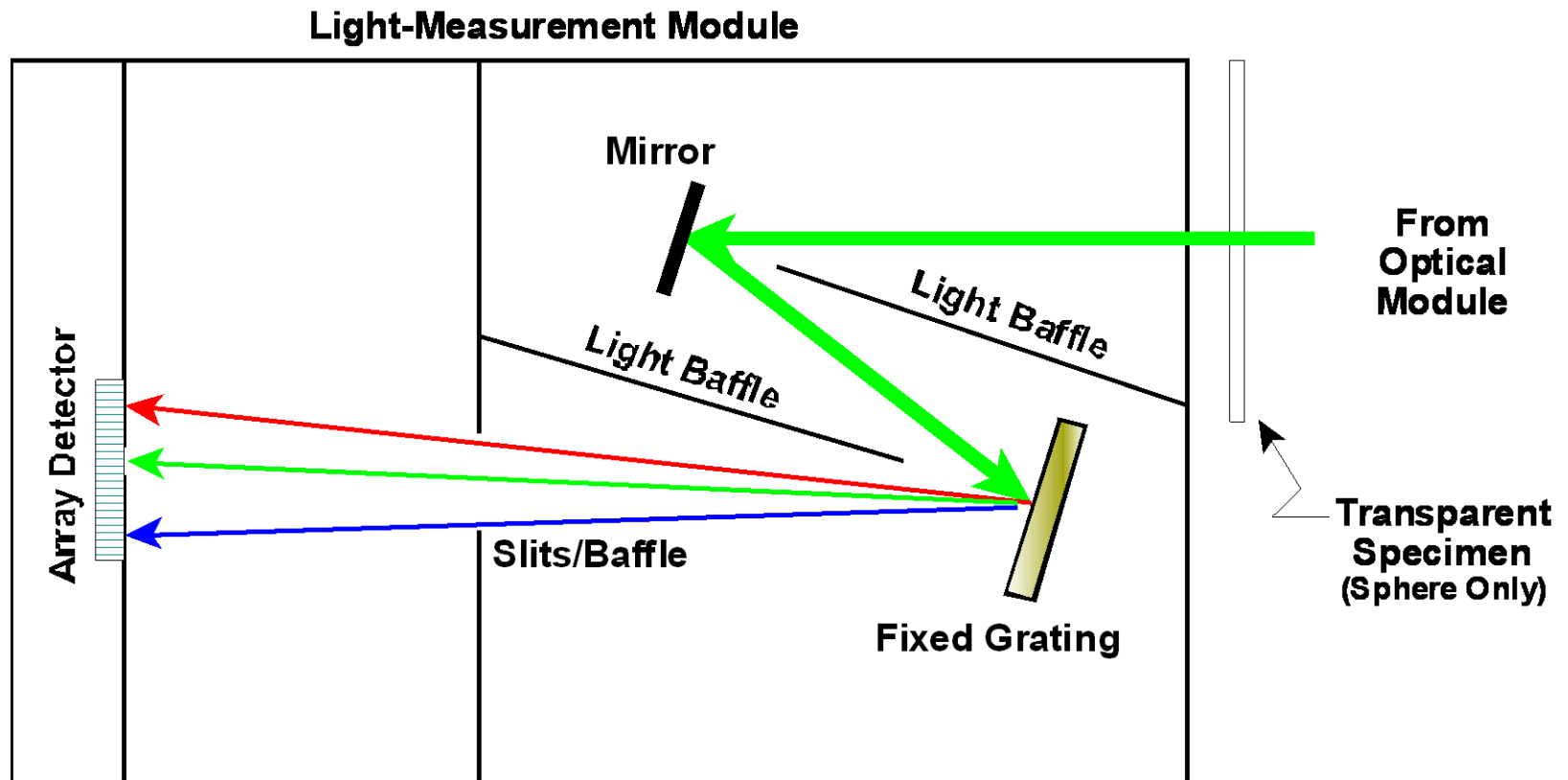


Specular Included

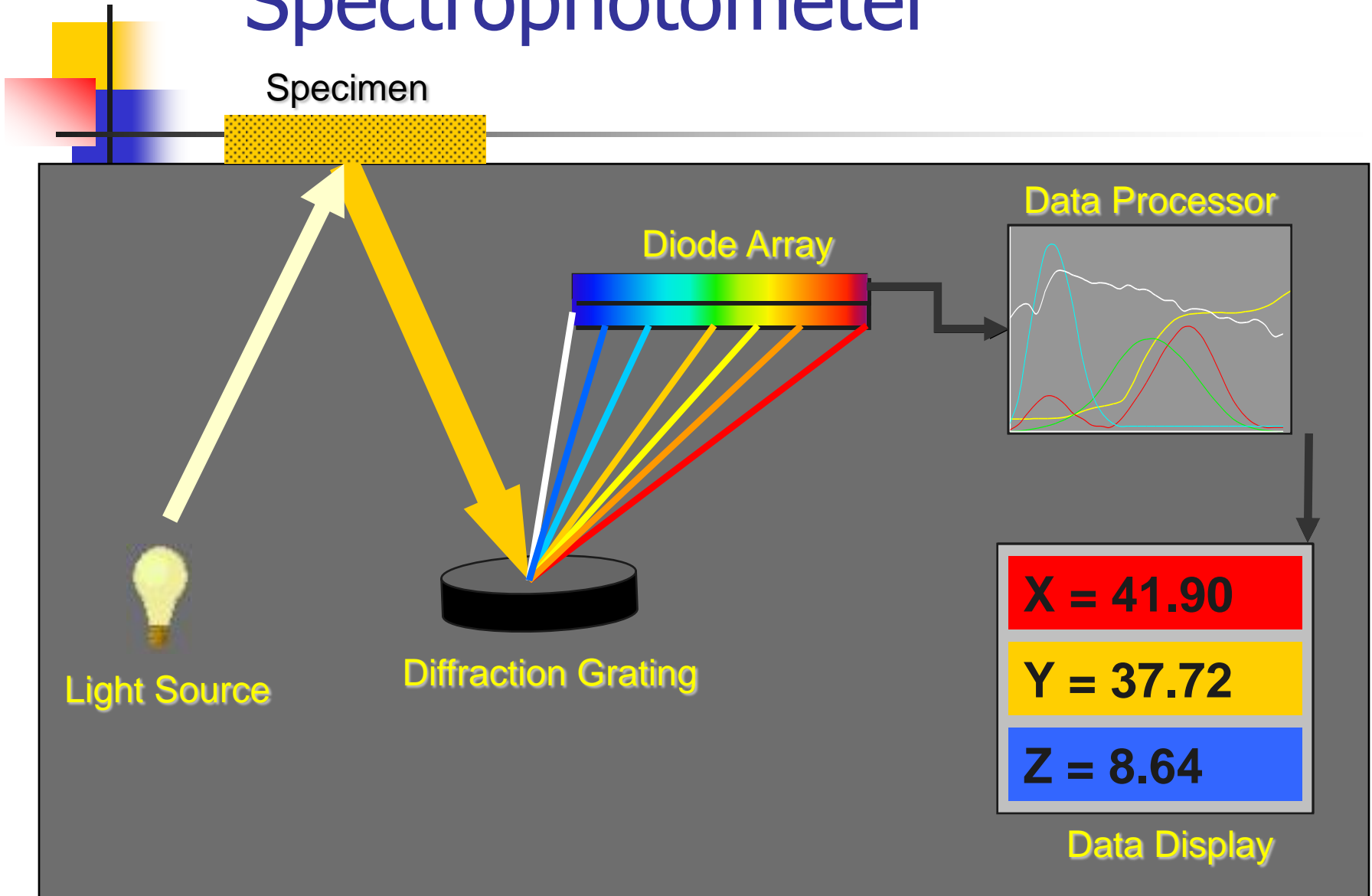


Specular Excluded

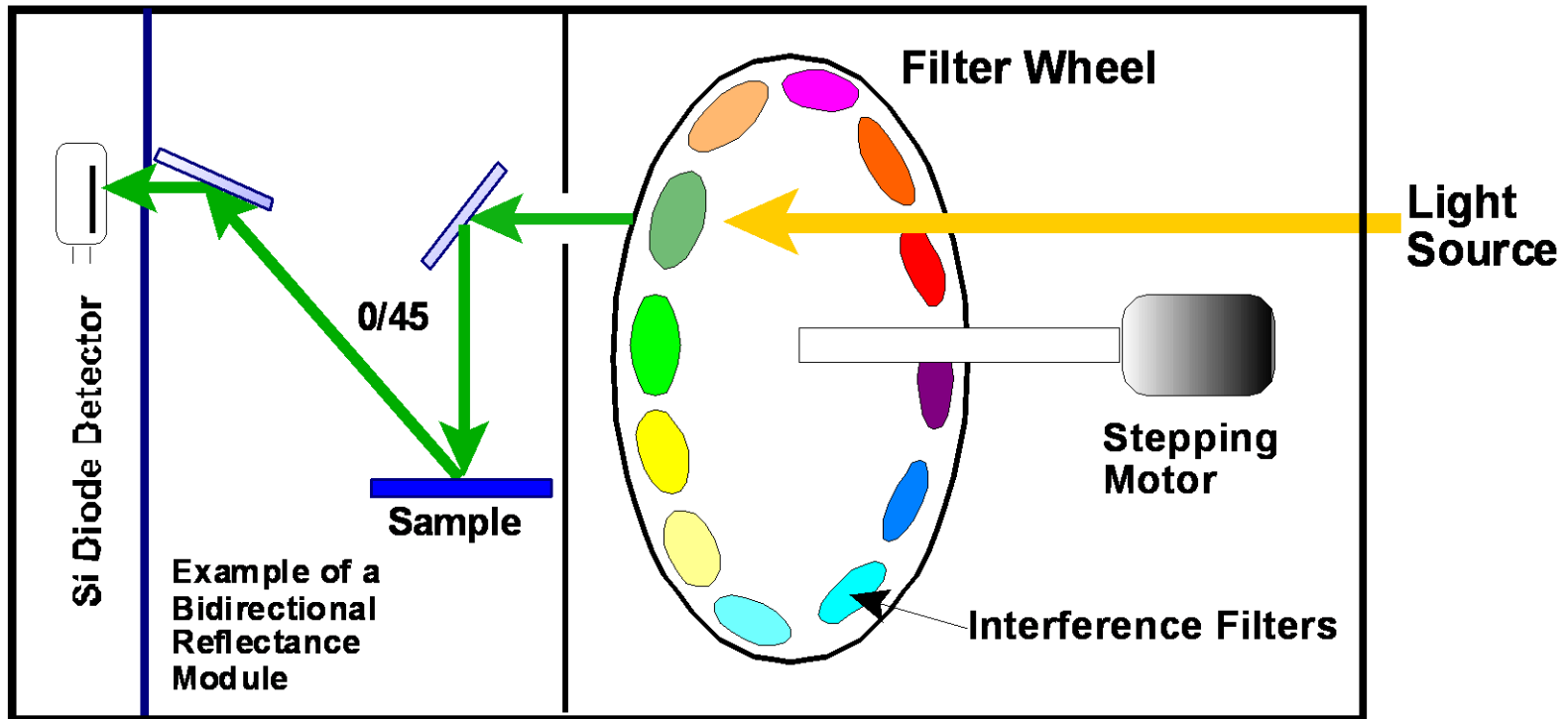
Schematic of a Silicon Diode-, or CCD- Array Color Spectrometer



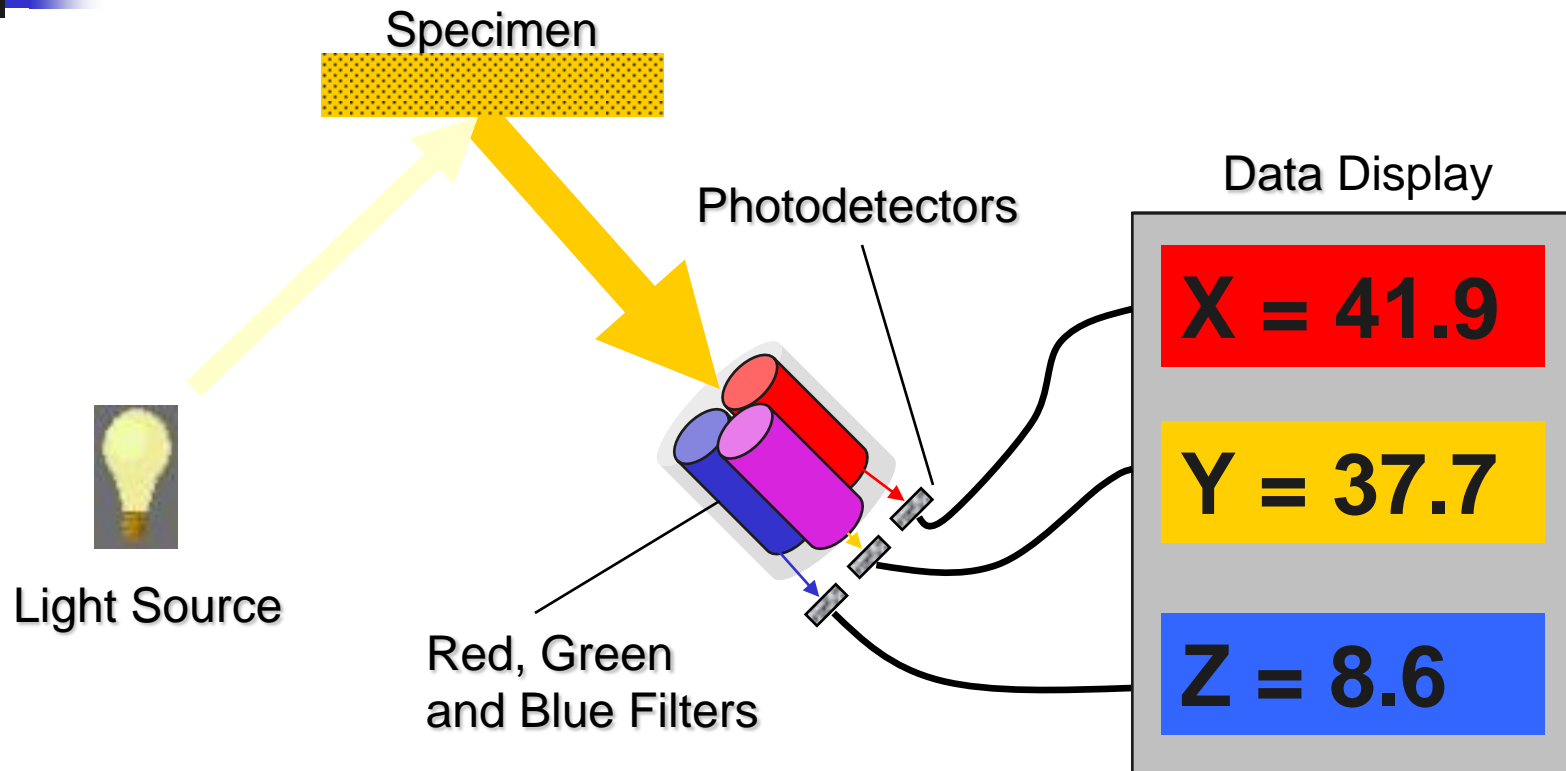
Measuring Color with a Spectrophotometer



Schematic of a Multi-filter Color Spectrometer



Measuring Color with a Tristimulus Colorimeter





Reflectance Method Issues

- Bidirectional (0/45 & 45/0)
 - Misalignment of incident/existent beams
- Hemispherical (Sphere)
 - Coating uniformity and ageing[‡]
 - Damage to sphere coating
 - Debris in sphere (especially bench-tops)
 - Small spheres with large port areas

[‡] Not as great an issue with TFE coatings such as Spectrolon®

Scanning Spectrometer Attributes



- Advantages

- ❖ High resolution (high scanning interval)
- ❖ Narrow bandpass
- ❖ Low stray light
- ❖ Transmittance measurements possible

- Disadvantages

- Slow data-acquisition speeds
- Wavelength train subject to mechanical distortion due to temperature excursions

Array Spectrometer Attributes



- Advantages

- ❖ Very high speed data-acquisition
- ❖ Wavelength (optical) train not subject to serious temperature distortion
- ❖ Transmittance possible in desktop models

- Disadvantages

- Stray light can affect shorter wavelengths
- Largest bandpass of the three types of spectrometers - which can be problem
- Small-pixel arrays have large wavelength intervals

Multi-filter Spectrometer Attributes



- Advantages

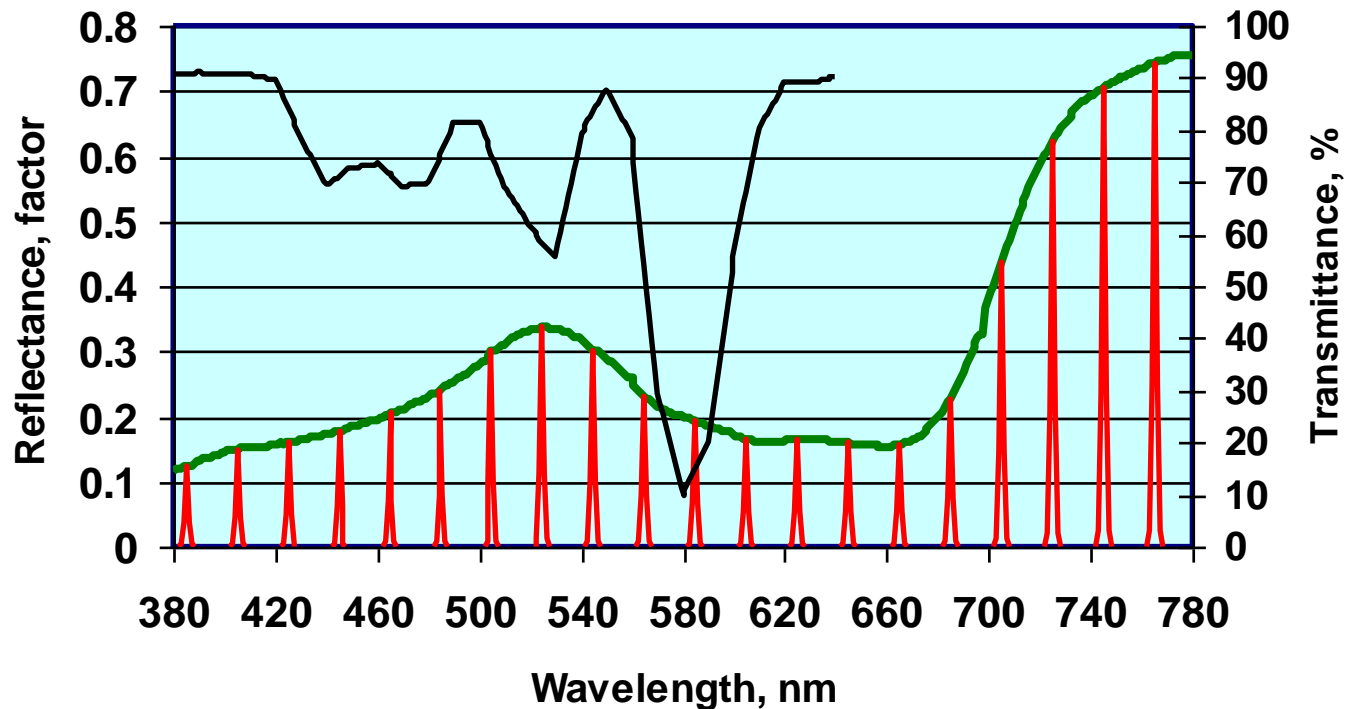
- ❖ Small bandpass - tied to FWHM of filters
- ❖ High speed data acquisition
- ❖ Low stray light
- ❖ Wavelength Stability (tied to interference filters)

- Disadvantages

- Large wavelength intervals[‡]
- Potential for temperature-induced distortion

‡ Sophisticated curve tracing employed to compensate

Spectra by a 20-nm-Resolution Multi-filter or Array Spectrometer



— Traced Curve — 20-nm Interval Measurement — Didymium Filter



Calibration of Sphere-Based Spectrometers (Scanning & Array)

- White porcelain tile furnished by manufacture for radiometric scale
- Green porcelain tile sometimes furnished by manufacture for **monitoring** colorimetric (e.g., wavelength) scale
- For higher-resolution instruments (e.g., scanning), a didymium (NIST SRM 2014) or a holmium oxide wavelength standard (NIST SRM 2034) is preferred
- Cavity light traps are usually used to set the zero reflectance scale



Calibration of Bi-directional Spectrometers (Array & Multi-filter Types)

- White reference (opal glass) sometimes furnished by OEM for 0/45 geometry for radiometric scale
- Black opal glass sometimes furnished for zero reflectance calibration
- A green spectral reference tile is sometimes furnished by OEM for wavelength calibration
- There are some OEMs who do not furnish a wavelength reference material



Scope of Accreditation Issues

- ASTM E308 should not be permitted on the scopes of testing laboratories.
- It may be acceptable if an OEM or system calibration laboratory places E308 on their scope – providing they use the standard in their calibration activities.
- Recommend that testing laboratories that participate in CTS for Test Nos. 408 and/or 409 place the appropriate ASTM Standard on their Scope of Accreditation.
 - E 1331 for sphere-based spectrophotometry
 - E 1347 for tristimulus filter colorimetry
 - E 1349 for 45:0 and 0:45 spectrophotometry

Traceability: Radiometric (Reflectance Scale)

NMI	Service(S) Tiles(T)	SRM	d/8	0/45	Wavelength, nm
NIST	S,T	2017	X	X ¹	200 – 700
NPL	S	42.05	X	X	320 – 780
NPL	T	42.07 ²	X	X	320 – 780
NRC	S	-	X	X	400 – 700
NRC	S ³	-	X		250 – 2500
PTB ⁴	S	-	X ⁵	X ⁶	380 - 720

¹Multiple angles also

²Spectrolon® reference

³Transmittance values

⁴Offered by BAM

⁵8/d also

⁶45/0 also

Traceability: Colorimetric (Wavelength Scale)

NMI	Service, S Tiles, T	SRM	d/8 & 0/45	Wavelength
NIST	T	2014 2034	Didymium Filter Holmium Oxide Filter	400 - 700
NPL	S, T	42.03	Meas. Service 12 BCRA Tiles, Green Tile	320 - 780
NRC	S	Will measure customer's green or other (BCRA) tiles		400 - 700 250 - 2500
PTB	S	BAM will measure customer's green or other (BCRA) tiles		380 - 720



Auditing: Equipment Issues

- Assessors should always check side- and top-loading spheres for debris (look inside), and
- Check the integrity of the sphere coating, and
- If specular-included values of L^* , a^* , b^* are “out” and specular-excluded values are “in” for proficiency test results (e.g., CTS), the sphere-completing spherical cap must be checked.
- Check condition of reference standards used for both d/8 sphere and 0/45 bidirectional instruments (white tiles/standards, green tiles, etc.)



Auditing: Calibration & Traceability Requirements – I

Typically OEMs burn into the D-PROM (firmware) the spectral reflectance values of the White Reference Standard. The calibration certificate furnished the Laboratory must contain the following information:

- For $d/8^\circ$ Sphere Instruments, the calibration values for both Specular Included and Specular Excluded, including X,Y,Z and the reflectance value for each pixel's wavelength assignment, or
- For $0/45^\circ$ Bidirectional Instruments, X,Y,Z and the $0/45^\circ$ reflectance value for each pixel's wavelength assignment
- Statement of Traceability
- Statement of Uncertainty
- Endorsement by citing the calibration laboratory's AB (if accredited)



Auditing: Calibration & Traceability Requirements - II

If a green tile is furnished to the laboratory, its calibration certificate must include

- For $d/8^\circ$ Sphere Instruments, the calibration values for Specular Included, including X,Y,Z and the reflectance value for each pixel's wavelength assignment, or
- For $0/45^\circ$ Bidirectional Instruments, X,Y,Z and the $0/45^\circ$ reflectance value for each pixel's wavelength assignment
- Statement of Traceability
- Statement of Uncertainty
- Endorsement by citing the calibration laboratory's AB (if accredited)



Auditing: Calibration and Traceability Requirements III

- Didymium or Holmium Oxide “filters” are sometimes furnished as a wavelength reference material. However, they will not be useful unless the resolution, or measurement interval, is 10 nm or better or unless sophisticated curve tracing is used.
- If a green tile is not furnished by the OEM, the test laboratory has the following options:
 - Obtain one from the OEM from whom they purchased the instrument, or
 - Purchase one from NPL, or
 - Have a green tile calibrated by NPL, NRC or PTB, or
 - If their color spectrometer possesses a diode- or CCD-array detection system with 40 pixels or more, they may purchase a Didymium or Holmium Oxide filter from NIST.



Auditing: Calibration and Traceability Requirements IV

- OEMs who furnish green tiles and/or didymium filters specify the maximum deviation of key reflectance and absorption peaks, respectively. When the wavelength is out of tolerance by greater than the specified maximum deviation, the instrument must be returned for service.
- Laboratories may purchase a medium green, medium gloss tile from a “bathroom tile store,” and have it calibrated by an acceptable NMI.
- Even more acceptable is the purchase of several colored tiles that may be submitted to an NMI for calibration.
- A green tile may be used in an internal quality control scheme by periodic measurements that are SQC charted to meet 5.9.1 of ISO/IEC 17025



Reference Materials Issue

In a recent decision by A2LA's Criteria Council, deficiencies will not be cited for lack of traceability of reference materials to an NMI through an accredited calibration provider pending the outcome of a thorough study of the issues.

This decision does not apply to reference materials that are not known to be traceable to the SI. Therefore, this decision does not apply to the measurement of color – and a reverse traceability process is required.

Once this study is completed and reference materials have been categorized, deficiencies will be cited for lack of traceability for certain reference materials that are not traceable to an NMI through an accredited provider.



Proficiency Testing (PT) (ISO/IEC 17025, ¶5.9)

- Primary Requirement to meet 5.9.b and ¶ 1.1 thru 1.3 of A2LA Policy on Proficiency Testing
 - Appropriate CTS programs for Color (5.9.b)
 - Any alternative formal, 3rd party proficiency test programs that may become available
- Secondary Requirements when not participating in a PT Program such as CTS
 - Round robin within a company's divisions (5.9.b)
 - Round robin between companies (5.9.b)
 - Internal repetitive testing (5.9.a, 5.9.c & 5.9.d)



A2LA Proficiency Testing Requirements - Testing

- Test labs measuring color must participate in available 3rd-party, commercial proficiency test programs every quarter for one year out of every four years
 - If CTS is chosen, lab must participate in Test #s 408 and/or 409, as relevant
- Lab must perform internal quality control testing in years in which 3rd-party PT testing is not performed
 - Lab may opt for performing 3rd-party PT every year



A2LA Proficiency Testing Requirements - Calibration

- Color calibration laboratories must participate in a 3rd-party proficiency testing program every year unless their number of disciplines are greater than two
 - Special rules apply if the calibration laboratory is accredited for more than four disciplines
- Calibration laboratories must initially measure an artifact (such as a green tile)



Major Issues for Testing Labs

- OEM manufacturers of color spectrometers are, with a single exception, not accredited to ISO/IEC 17025 for calibration of their white reference standards
 - This results in deficiencies for laboratories using OEM equipment from manufacturers whose calibration laboratories are not accredited
- No OEM manufacturer claims traceability for “color” – i.e., only for their white reference tiles



SUMMARY

- Calibration Issues
 - Accredited
- Calibration Certificate Issues
 - Endorsement
 - Traceability Statement
 - Statement of Uncertainty
- Sources of Error
 - Stray light
 - Band-pass errors