Applying Colorimetry to Minerals: Limitations and Applications

Kathryn Royce, D.Phil. Candidate, University of Oxford

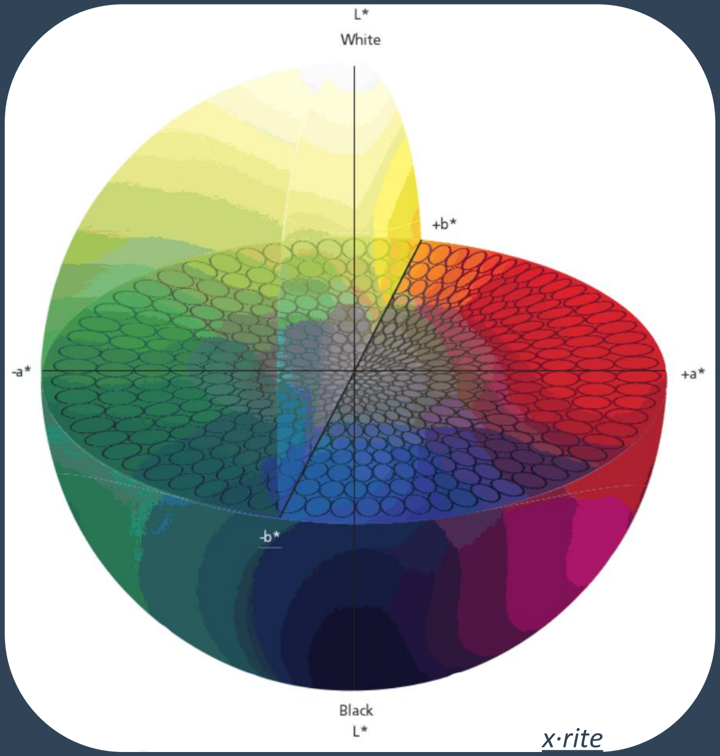
a Very Brief Intro to Colorimetry

Colorimetry

- Science of color measurement
- Creates numerical values to plot in color space
- Reproduces color of sample under specific viewing & lighting conditions
- Enables quantifying color & color difference
  - between objects
  - in one object over time

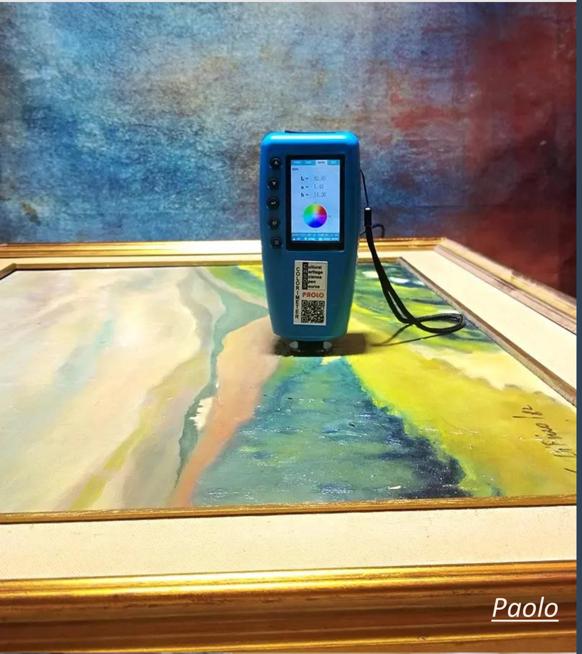
Color Space

- 3D geometrical shape
- Fits all possible colors
- Examples:
  - Pantone
  - CIELAB
  - RGB
  - HSV / HSL
  - CYMK



'One of the ways to simplify color specification is to reduce the problem to one of color matching.'
- Berns 2019

The Textile Conservation Centre Foundation



Paolo

Smithsonian Air & Space

Colorimetry in Heritage

Quantifying change over time

- light
- pollutants
- conservation treatments

Previously applied to:

- artworks
- mosaics
- wall paintings
- building materials
- textiles
- herbaria

Pros:

- non-destructive
- portable
- easy to use
- increasingly affordable

the Experiment

- Can colorimetry be successfully applied to minerals?
- Which equipment works best?
- Which measurement parameters are best for minerals?


Color Card 1
Mudstone
Baryte
R
Aventurine
T
T
R
Rose Quartz
Hematite
20
Chalcanthite
19
8
Calcite
10
Onyx
Pyrite - cubic
Pyrite - aggregate
Pyrite - tarnished
Color Card 2

Samples

Equipment

Model	Konica Minolta CM-700d		Nix Pro 2
Device Type	Spectrophotometer		Colorimeter
Dimensions	73 x 211.5 x 107 mm		60 x 60 x 42 mm
Weight	~550 g		43 g
Geometry	di:8°, de:8°		0°/45°
Specular Component	SCI & SCE		SCE
Measurement Area	3mm	8mm	14mm
Aperture Diameter	6mm	11mm	14.5mm
Mask Diameter	23mm	23mm	20mm
Illuminant	D65	D65	D65
Observer	10°	10°	10°

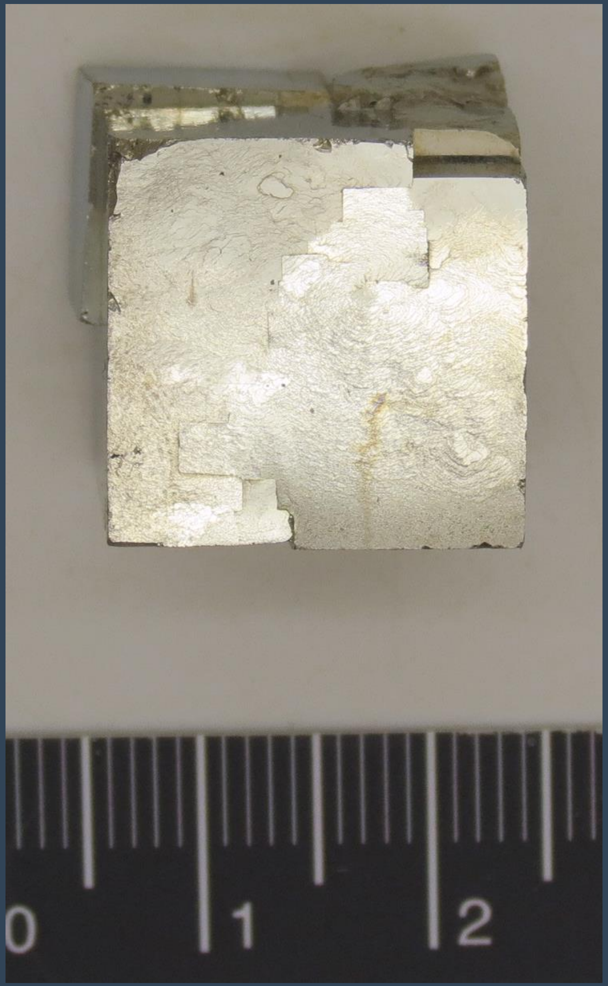
Apertures

medium small

reduced

Phase	Equipment	Aperture	Diameter (mm)	Specular Component
1	Konica Minolta	small	6	SCI & SCE
2	Konica Minolta	reduced small	3	SCI
3	Konica Minolta	medium	11	SCI & SCE
	Nix Pro	medium-large	14.5	SCE

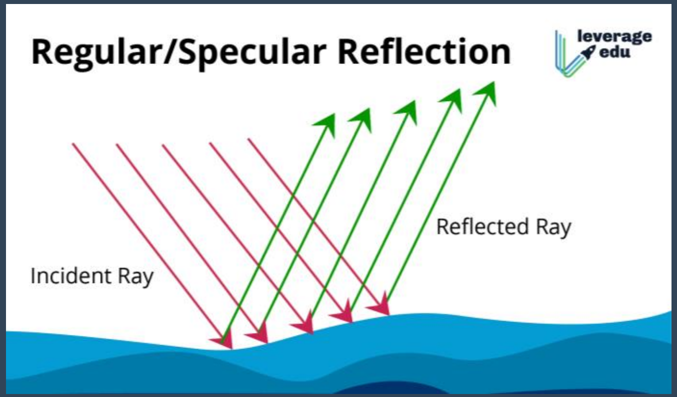
Specular Component



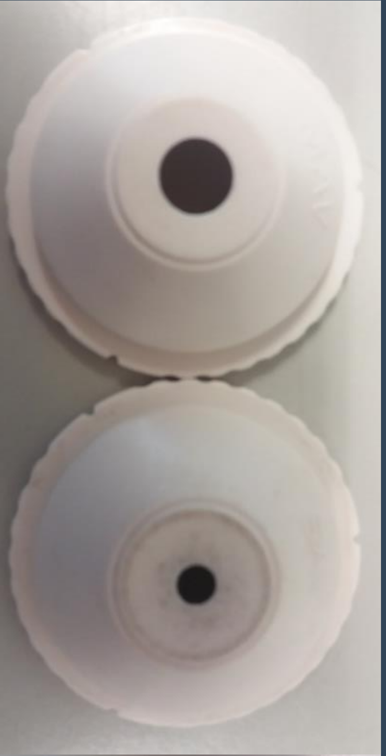
- Whether specular reflectance included during measurements

SCI	SCE
included	excluded

- Examples of specular reflectance
  - reflections in mirror or water
  - glitter's 'flash of light'
  - highlight of a shiny object



- We naturally try to 'remove' specular reflectance to gauge object's color



Summary of Parameters

<u>Constants</u>

- Color Space: CIELAB
- Illuminant: D65 (ave. daylight)
- Observer: 10°

Phase	Equipment	Aperture	Aperture Abbreviation	Diameter (mm)	Specular Component
1	Konica Minolta	small	SAV	6	SCI & SCE
2	Konica Minolta	reduced small	rSAV	3	SCI
3	Konica Minolta	medium	MAV	11	SCI & SCE
	Nix Pro	medium-large	MAV	14.5	SCE

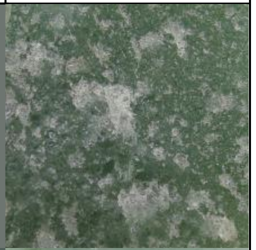
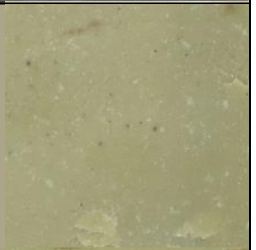
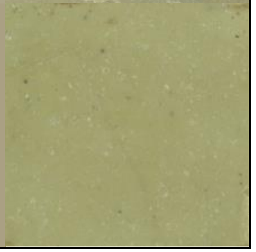
Pseudo-Object Colors

- Digital visualizations of measured color
  - XYZ => RGB
- Konica Minolta SpectraMagic NX: ‘Pseudo Colors’

Color Cards

Device	Konica Minolta					Nix Pro	Intentional
Specular Component	SCI			SCE			
Aperture	rSAV	SAV	MAV	SAV	MAV	MAV	
cc.1.a							
cc.2.a	—						
cc.1.b							
cc.2.b	—						
cc.1.c							
cc.2.c	—						
cc.1.d							
cc.2.d	—						
cc.1.e							
cc.2.e	—						
cc.1.f							
cc.2.f	—						
cc.1.g							
cc.2.g	—						
cc.1.h							
cc.2.h	—						

Minerals: green

Device	Konica Minolta					Nix Pro	Image of Sample Area
Specular Component	SCI			SCE			
Aperture	rSAV	SAV	MAV	SAV	MAV	MAV	
m.1.r							
m.1.t							
m.6.o							
m.6.r							

Aventurine
translucent

Mudstone
opaque

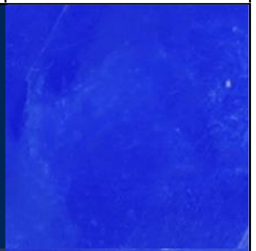
Minerals: white / orange

Device	Konica Minolta					Nix Pro	Image of Sample Area
Specular Component	SCI			SCE			
Aperture	rSAV	SAV	MAV	SAV	MAV	MAV	
m.2.8							
m.2.10o							
m.2.10w							
m.7							

Calcite
translucent

Baryte
opaque

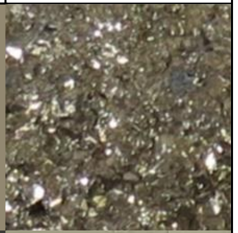
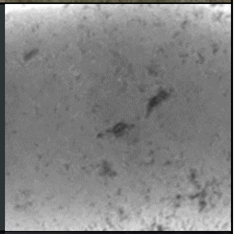
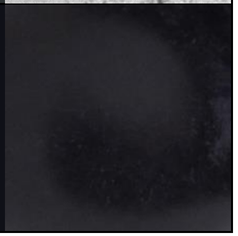
Minerals: blue & pink

Device	Konica Minolta					Nix Pro	Image of Sample Area
Specular Component	SCI			SCE			
Aperture	rSAV	SAV	MAV	SAV	MAV	MAV	
m.3.19							
m.3.20							
m.5.r							
m.5.t							

Chalcanthite
translucent

Rose Quartz
opaque

Minerals: metallic

Device	Konica Minolta					Nix Pro	Image of Sample Area
Specular Component	SCI			SCE			
Aperture	rSAV	SAV	MAV	SAV	MAV	MAV	
m.4.a							
m.4.c							
m.4.t							
m.8							
m.9							

Pyrite

Hematite

Onyx

the Results

- **Best Performer**: Konica Minolta CM-700d & SCI
  - ➢ Sample type: 2D = SAV | 3D = MAV

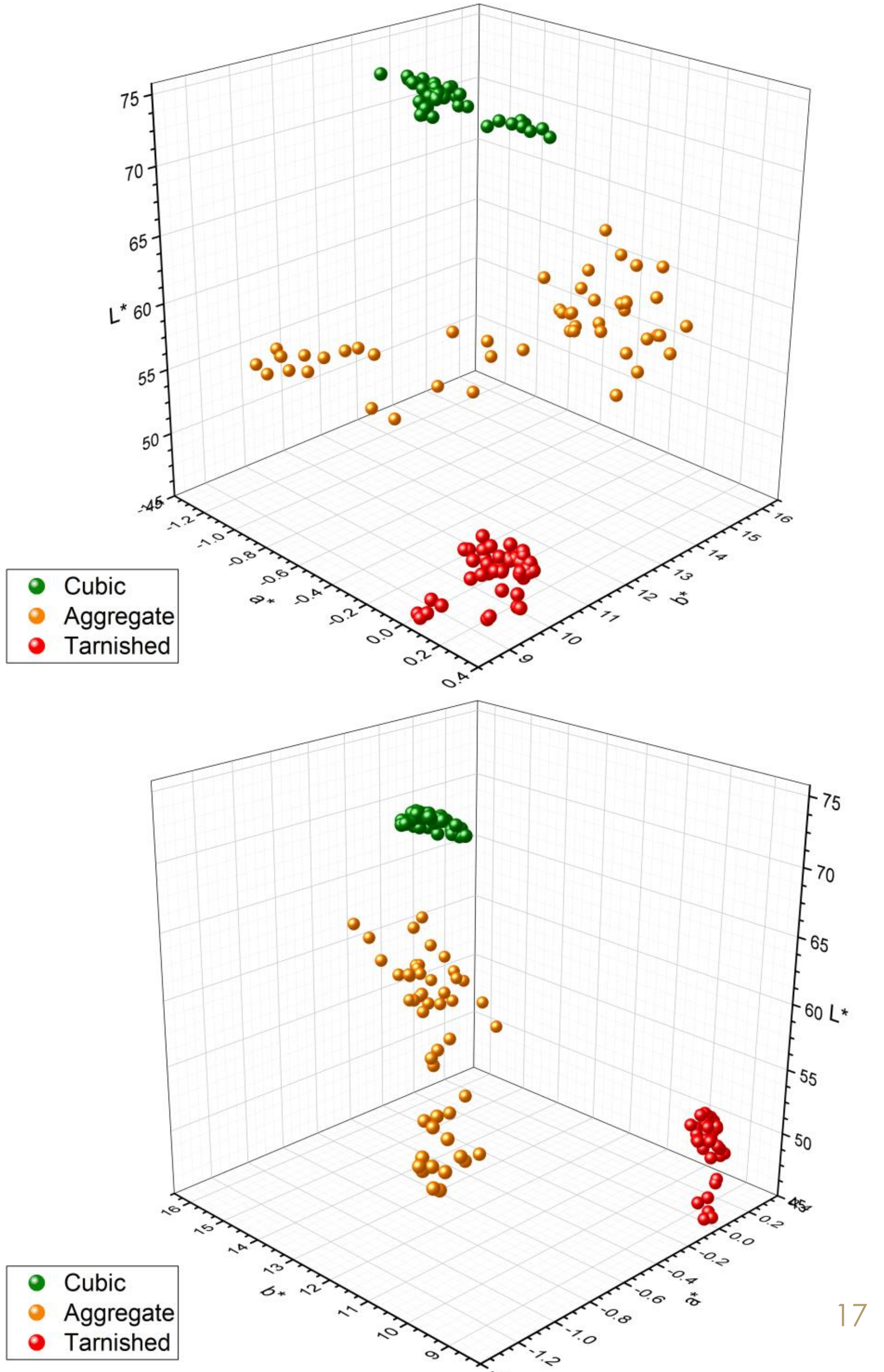
- **Worst Performer**: reduced aperture (rSAV)
  - ➢ statistically mediocre
  - ➢ produced greyer colors for all samples
  - ➢ do NOT reduce aperture if useful & accurate color data is desired

- **Up & Coming**: Nix Pro 2
  - ➢ great for 2D samples; produced best colors
  - ➢ ideal non-destructive equipment: cost, size, usability
  - ➢ worst performer for minerals
    - ➢ traditional spectrophotometers best for metallic or high luster objects

Next Steps

- great success with metallic minerals
- could accurately represent various stages of tarnish

- pilot study examining correlation between pyrite color & tarnish by utilising an AI algorithm
  - see poster for more details
    #307 - PyrΔTE: an AI-based pyrite tarnish probability generator
  - Reference for Mineral Care
    https://mineralcare.web.ox.ac.uk/pyrate



the Field Museum, Chicago

Conclusions

1. Possible to use colorimetry to monitor light-induced color changes & tarnish formation
   - ✓: opaque & metallic
   - **X**: transparent & translucent

2. Important to optimize parameters for application
   - not a ‘one size fits all’ approach
   - ideal parameters may be different than anticipated
   - worth critical evaluation to ensure collecting best data for application

the Systematic Display Gallery at the Natural History Museum, London

Further Information

Books

- R.S. Berns 2019 – Billmeyer & Saltzman's Principles of Color Technology, 4th ed.
- R.G. Kuehni 2003 – Color Space & its Divisions

Reference for Mineral Care

- http://mineralcare.web.ox.ac.uk/
- http://mineralcare.super.site/

Youtube Playlists

- Color & Perception
- Conservation & Object Care
- Minerals
- Museums & Culture

Thank you for listening!

This experiment is an output of a collaborative doctoral research project, supported by collaborators from the following institutions:

- University of Oxford, School of Geography & the Environment – Prof. Heather Viles
- National Museum Cardiff – Dr. Jana Horak, Tom Cotterell
- National Museums Liverpool – Dr. Christian Baars
- BSRIA Ltd. – Tom Gagarin
- OR3D – James Earl

The PhD project is part of the Science and Engineering in Arts, Heritage, and Archaeology Centre for Doctoral Training (SEAHA CDT).

Funding has been provided by:

- The Engineering and Physical Sciences Research Council (EPSRC)
- The Barbara Whatmore Trust
- The Pilgrim Trust
- The National Conservation Service

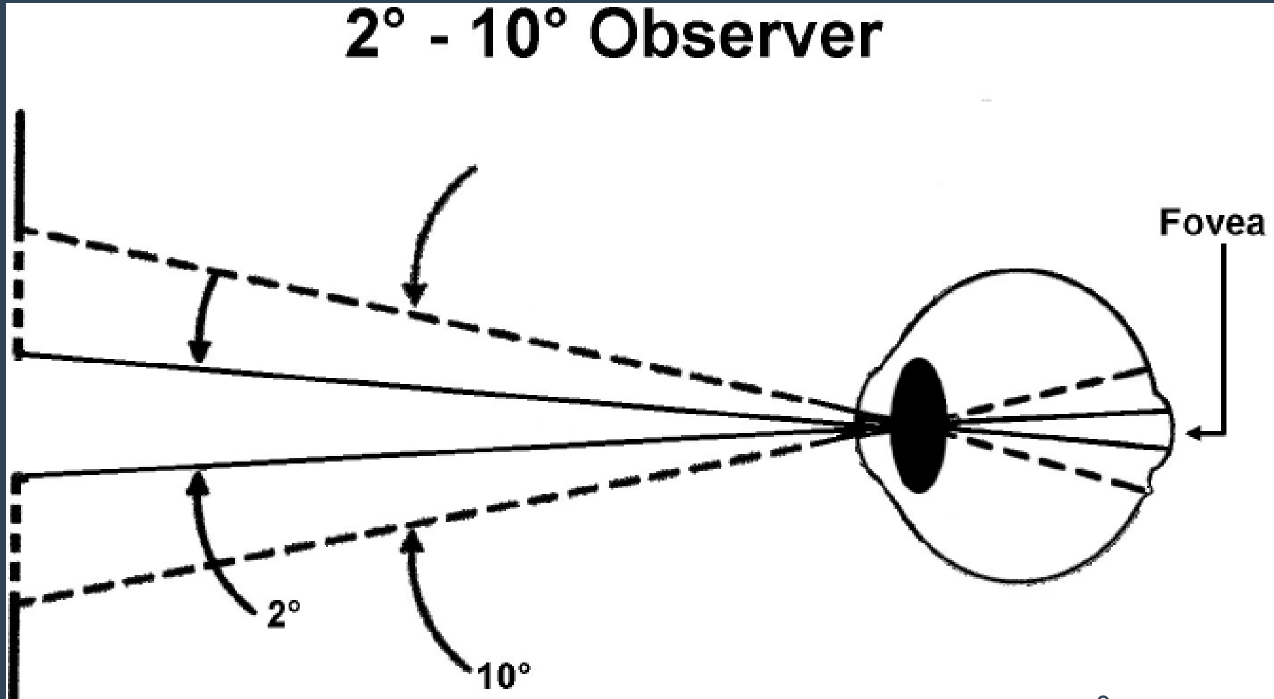
Email: kathryn.royce@ouce.ox.ac.uk

CIE Standard Illuminant D65

- ~6500°K CCT
- ave. daylight in northern hemisphere (Judd et al. 1964)
  - Rochester, NY, USA; Ottawa, Canada; Enfield, England (41° –51° N lat.)
  - both direct sunlight & light diffused by a clear sky

1964 CIE Standard Observer

- 10° field of view
- firmer statistical foundation than 1931 2° observer
- Higher precision => large-field color matching
- Used by most industries that produce colored products



Source

Berns 2019: 61

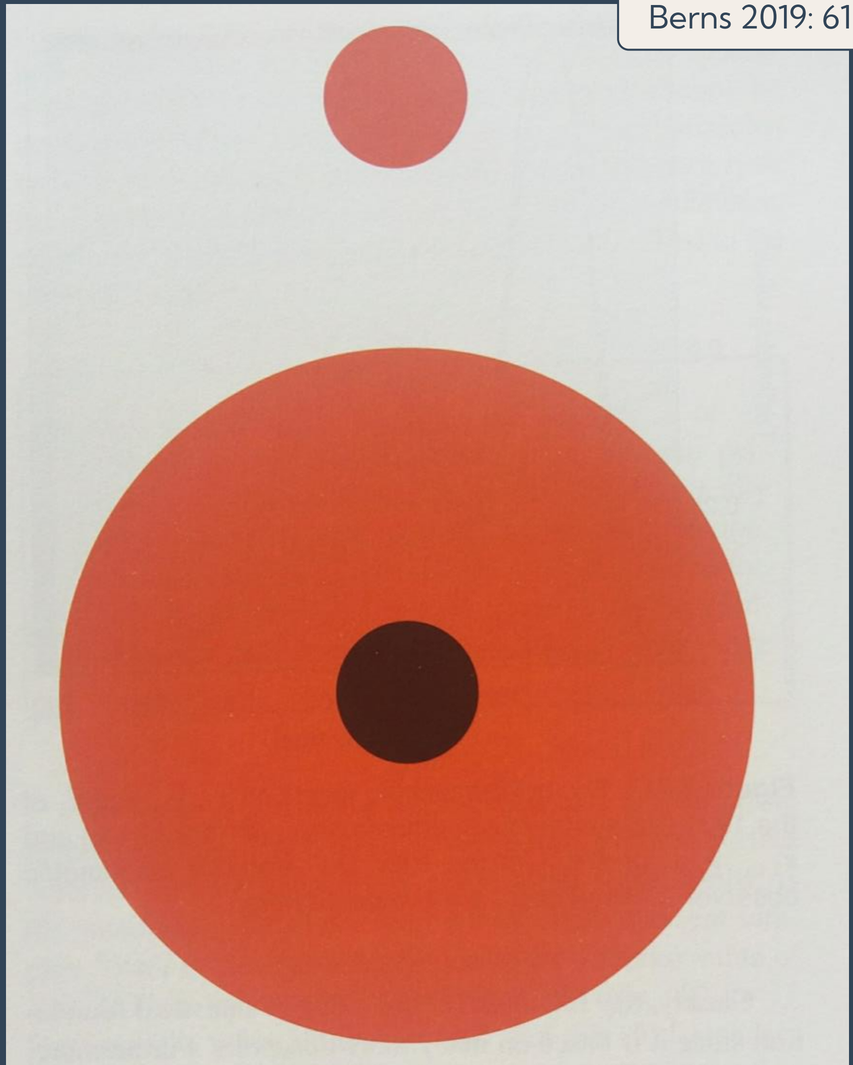


Figure 4.20 At a normal viewing distance of 0.5 m (19.7 in.), the circle on the top represents the 2° field on which the 1931 CIE standard observer is based. The figure on the bottom is the 10° field on which the 1964 CIE standard observer is based. The center of the 10° field is black to remind us that the 2° field was ignored (Stiles and Burch 1959) or masked (Speranskaya 1959) so that the central 2° was not included in the visual data.

Choice of geometry affects sample's measured color!

Berns 2019: 117

1931 Standard Geometry
- bidirectional: 45°:0° & 0°:45°
- illumination at 45° from normal angle
- view along normal angle => excludes specular reflection

Integrating sphere: d:0° & 0°:d
- hollow metal sphere coated with highly reflecting diffuse material (barium sulfate or PTFE)
- collects all light reflected from sample surface, which is placed against opening into sphere (port)
- if normal angle maintained, any specular reflection exits either through the source or detector port

Most spheres offset from the normal angle by ~6–8°
- By placing a specular port at opposite angle, specular reflection can be included/excluded from measurement by placing a material identical to the sphere's interior or a black trap (respectively) at specular port
- **di: 8°** = diffuse influx* & 8° efflux with SCI
  - any specular reflection & texture not observable (i.e., uniform white light added to visual evaluation)
- **de: 8°** = diffuse influx* & 8° efflux with SCE
  - specular reflection excluded, but not necessarily all its 1^{st}–surface reflections; texture not observable
- *corresponds to completely diffuse illumination (e.g., cloudy sky, uniform artificial illumination)

Berns 2019: 115–118

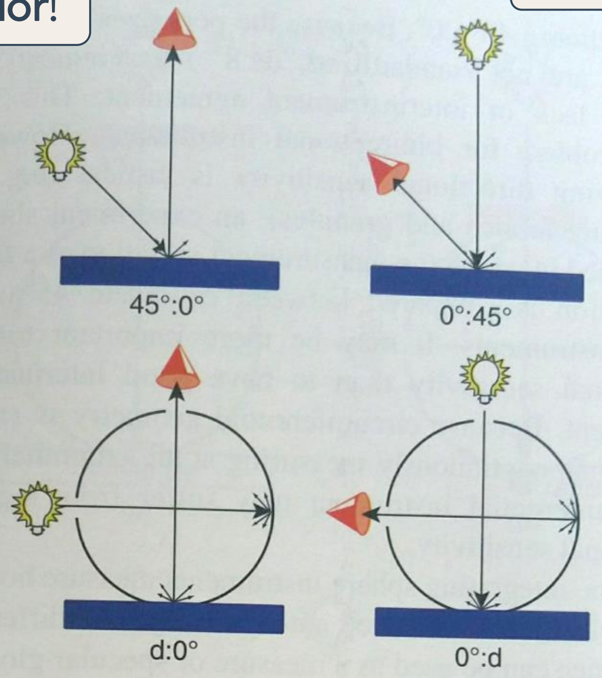


Figure 6.12 Simplified diagrams of the four CIE recommended geometries for color measurement.

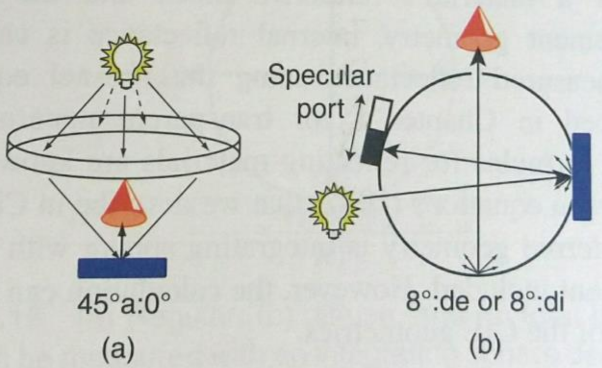
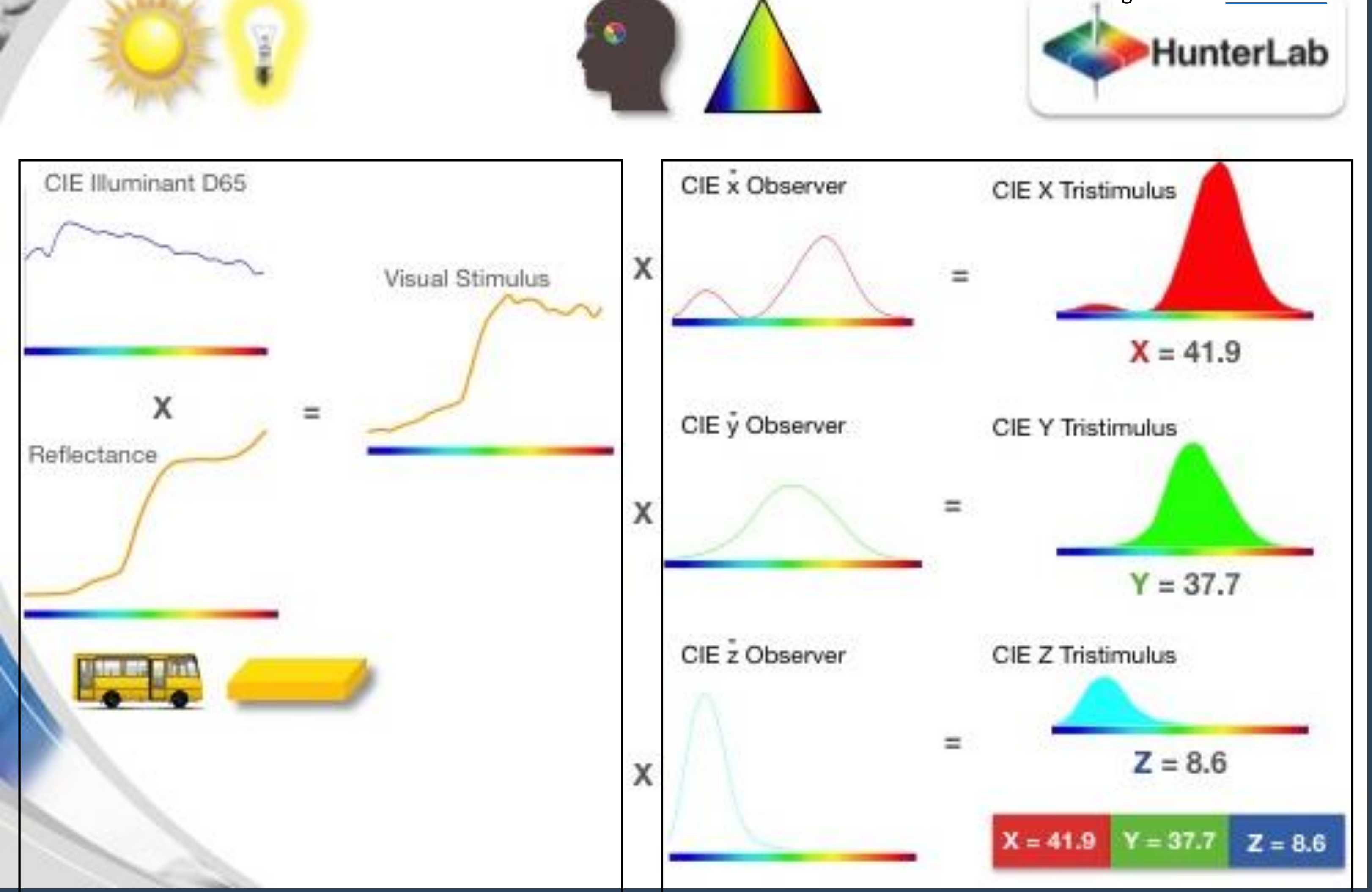


Figure 6.13 (a) Bidirectional annular geometry and (b) integrating sphere geometry where the specular component can be included or excluded (as shown).

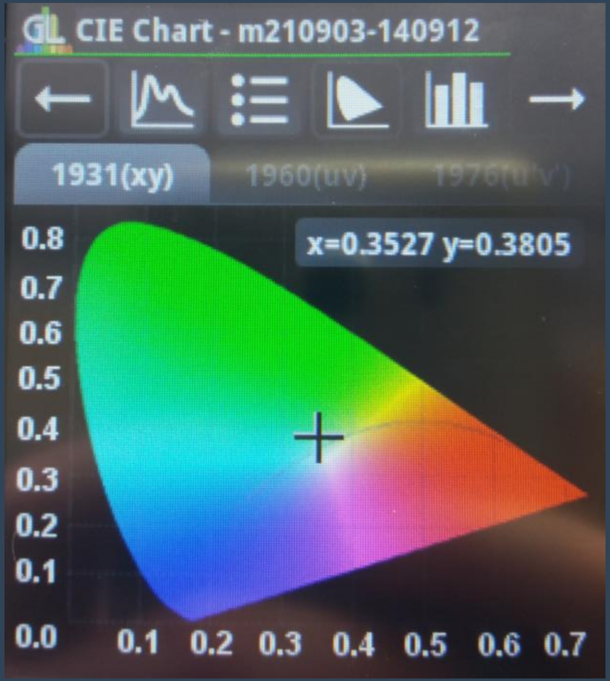
image source: HunterLab



1. Collects spectrum of light

2. Calculates tristimulus values (X, Y, Z) for selected standard observer

RGB



3. Values converted to desired color space

CIELAB