Optical Measurements and Standard Materials for Color and Appearance

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NIST

NIST Workshop on Metrology and Modeling of Color and Appearance

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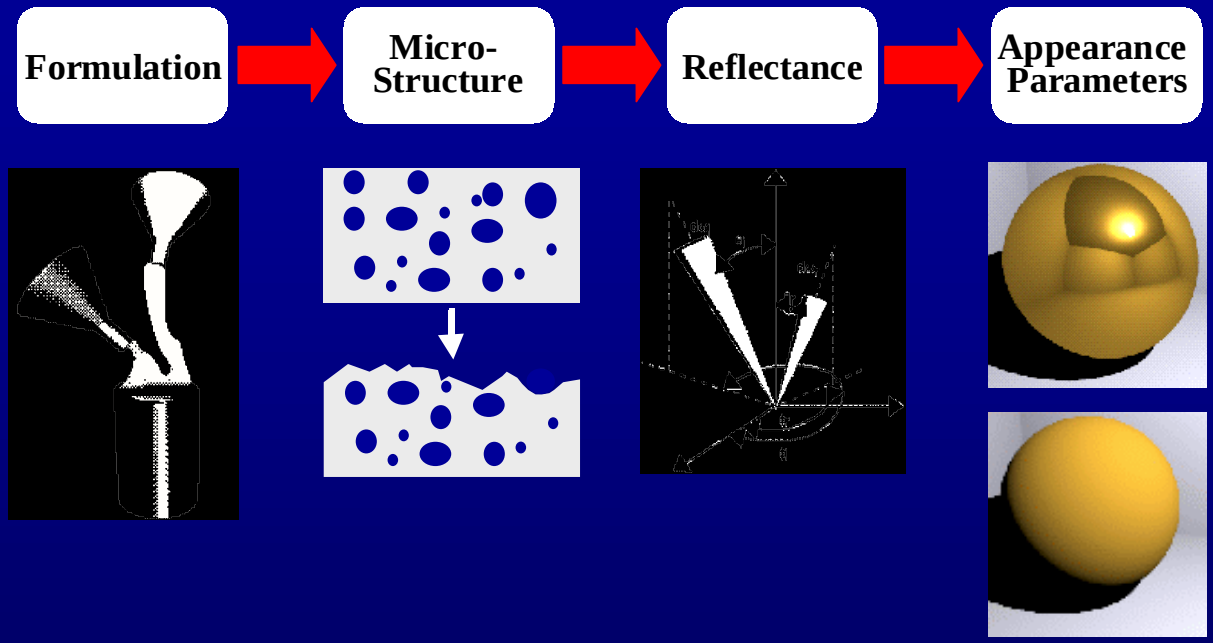
Outline

- Physics Laboratory Goals for the Competence Project
  - Optical Characterization of Coatings
  - Specular Gloss
  - Reflectance Colorimetry
- Interference (Pearlescent) Pigments

Physics Lab. Goals for the Competence Project



- Measured reflectance is used to refine models derived form surface microstructure - Li-piin Sung (NIST) and Egon Marx (NIST)
- Test BRDF measurement protocols to be used in computer rendering to create accurate visual representations - Michael Metzler (ISCIENCES, Corp.) and Gary Meyers (University of Oregon)

Physics Lab. Goals for the Competence Project

- Develop instrumentation and calibration services for the complete characterization of material color and appearance
  - Reference Goniophotometer and Primary Standard for Specular Gloss
  - Reference Reflectance Colorimeter and Measurement Assurance Program (MAP)

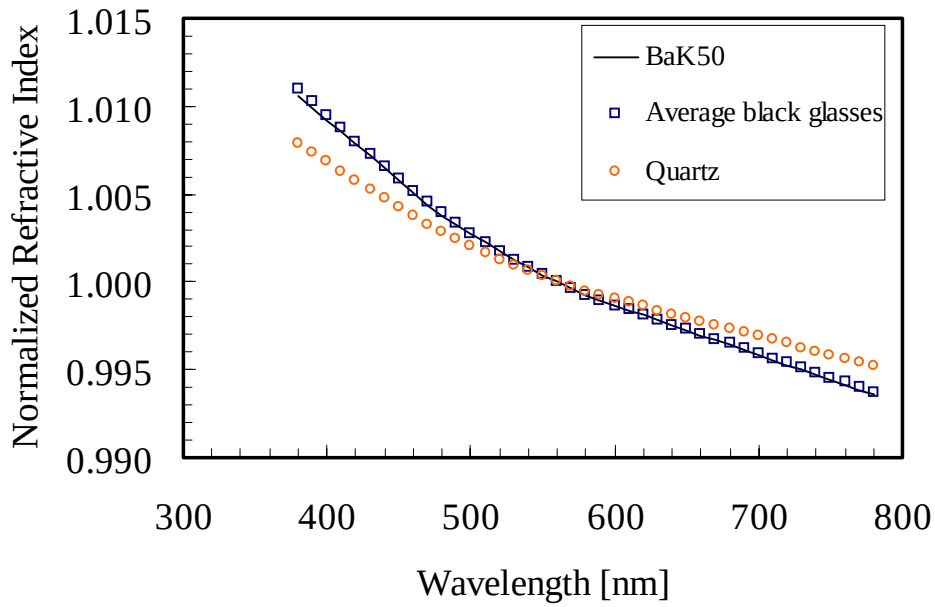
Specular Gloss

- Measurement capabilities
  - specular gloss (ISO 2813 and ASTM D523) (20°, 60°, and 85°)
  - reflection haze
  - bi-directional reflectance and transmittance measurements at angles of 0° to 85° (ASTM E167)
  - others specular geometries such as 30°, 45°, and 70°
- Expanded uncertainties (k=2): 0.3 %
- New primary specular gloss standard
- NIST-NRC Canada specular gloss scale intercomparison
- Shortcomings of specular gloss measurements
- Special test calibration services

NIST Reference Goniophotometer

NIST New Primary Gloss Standard

- Highly polished clear, crown glass (BaK50)
- 6° wedge
- High purity optical glass with high chemical and mechanical durability
- Calibration methods



Method	Standard Geometry 20°	60°	85°
Refractive index, n_D	100.2	100.1	100.0
Refractive index (380nm- 780nm)	100.8	100.5	100.0
Absolute luminous reflectance	100.9	100.7	-----

NIST-NRC Canada Specular Gloss Scale Intercomparison

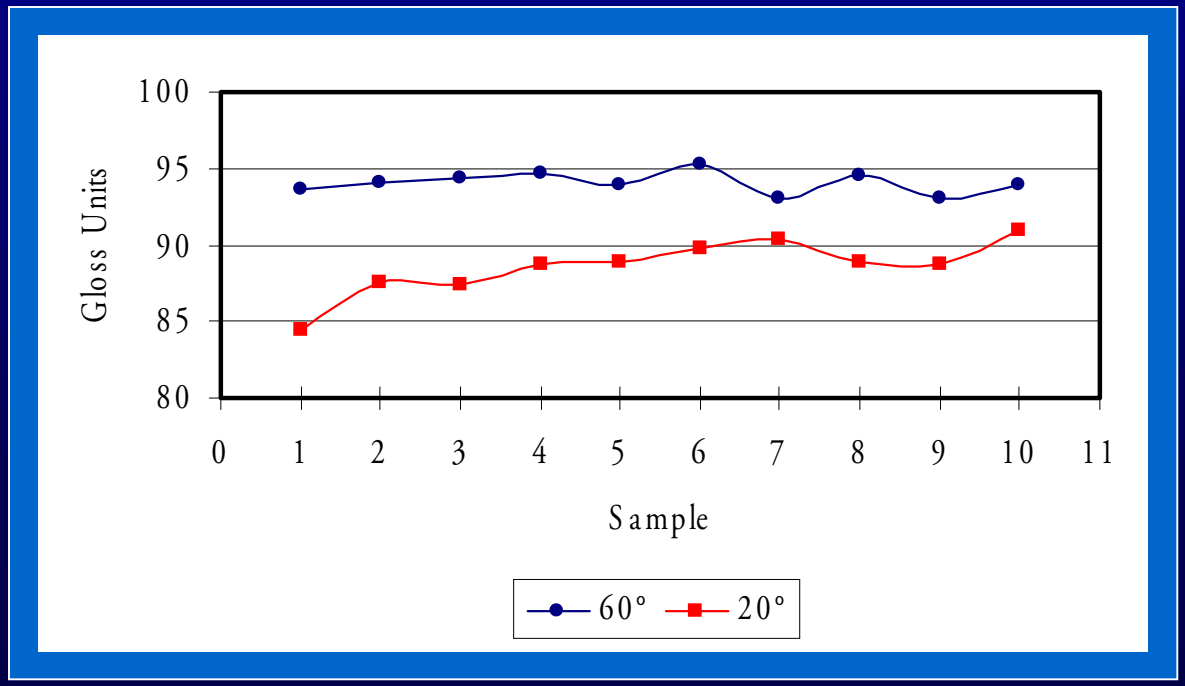
- Measurements:
  - three recommended geometries for the paint industry
    - 20°, 60°, and 85°
- Samples:
  - four pieces of highly polished black glass with high gloss values
  - one piece of black glass with medium gloss value
  - one piece of white tile with low gloss value

20° Specular Geometry

Gloss Level	NIST	NIST – NRC Canada	Expanded Unc. (k=2) NIST & NRC Canada
High	92.56 ± 0.27	0.04	0.41
	92.96 ± 0.20	0.16	0.37
	92.70 ± .32	0.20	0.45
	92.93 ± .18	0.07	0.50
Medium	65.95 ± .36	1.57	0.39
Low	16.00 ± .18	0.03	0.53

Shortcomings of Specular Gloss

- Fails to discriminate between samples in the high gloss end
- Example: ACT Orange peel set (10=best) (60° & 20°)



Summary
- Specular Gloss -

- Reference goniophotometer
- Primary specular gloss standard
- Special test calibration service for 20°, 60°, and 85°
  - Technical contact: Maria Nadal
    phone number: 301-975-4632
    email: maria.nadal@nist.gov
- Next step: Image formation / open discussion

Reflectance Colorimetry

- Develop Measurement Assurance Program (MAP)
  - Agreement between instruments falls short of the requirements of industry
- Develop NIST reflectance colorimeter
  - Standard industrial measurement geometries (45°/0°, full goniometer, and ~0°/d)
  - Color discrimination $\mathbf{\Delta E^*_{ab} \leq 0.5}$
- Develop calibration program

Color Measurement Assurance Program

- Reflectance Colorimetry Set
  - 14 BCRA ceramic tiles, current industry color standards
    - Uniformity (60 mm measurement area)
    - Thermo-chromaticity (polychromatic irradiation, darkening effect)
    - Front surface: **glossy** or matte
    - Individual calibration
    - Fluorescence (λ of illumination < 300 nm)
    - Durable and stable
  - Diffuse white standard, Spectralon™

Color Measurement Assurance Program

- Measurement parameters
  - λ = 380 nm to 780 nm at 5 nm steps
  - θ_i / θ_v = 45°/0°
  - Reflectance factor and color calculations
- Results from customer measurements of BCRA tiles will be used to diagnose measurement problems
  - Stray light, wavelength accuracy, random noise, bandpass, reflectance scale

Color Calculations

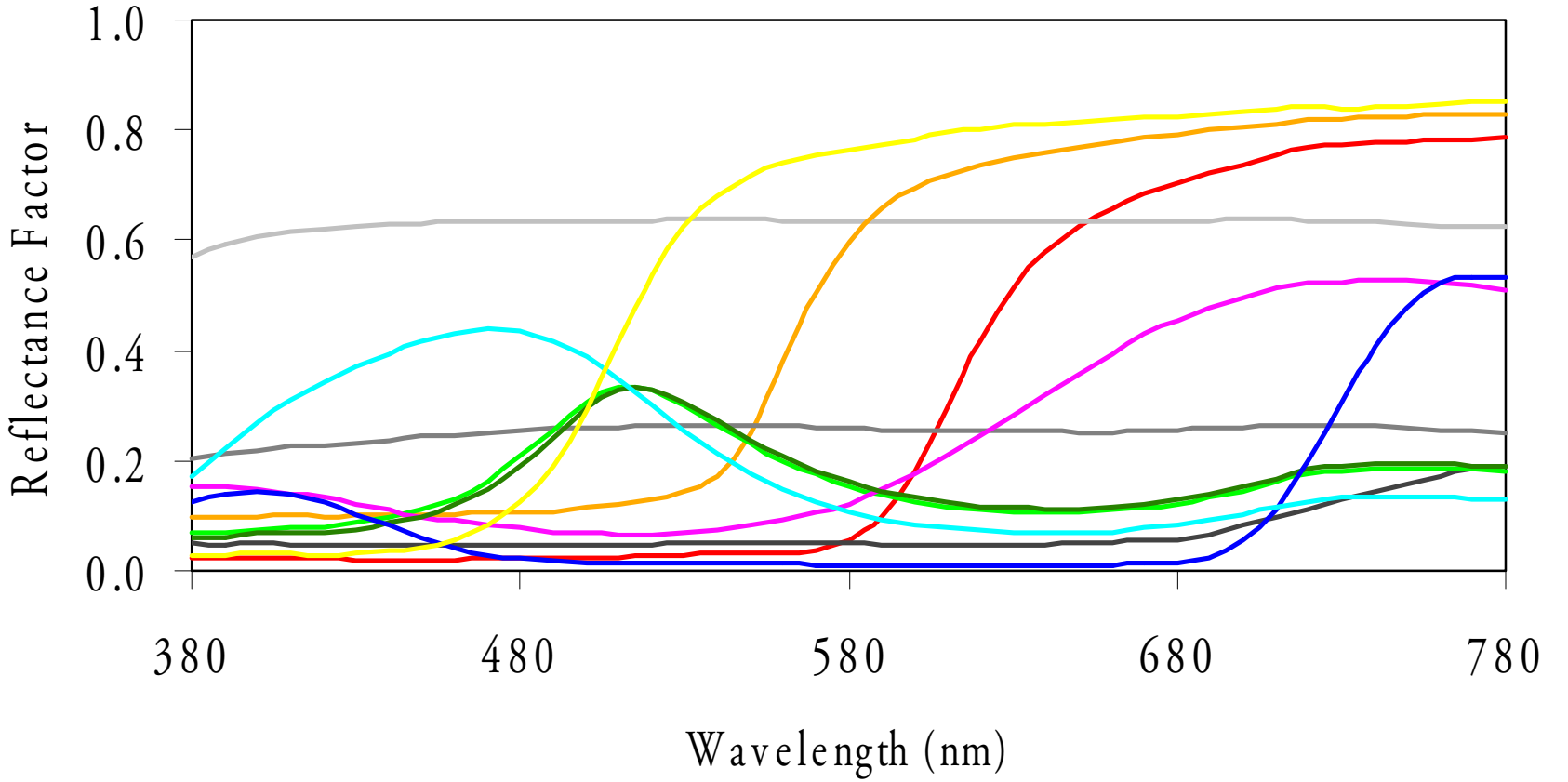
- Tristimulus values and chromaticity coordinates

$$X = k \sum_{380}^{780} \bar{x}_\lambda \, R_\lambda \, S_\lambda \, \Delta\lambda$$

  - standard CIE illuminants C and D65 (S_λ)
  - Reflectance factor of samples relative to a perfect reflecting diffuser (R_λ)
  - Standard CIE observer to correlate with visual observation (x, y, z)
- Color Calculation: approximately uniform space , e.g. CIELab (differences are calculated from the uncertainty in R(λ))

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

BCRA Reflectance Factors



Stray Light and Wavelength Calculation

Color Tile	Stray Light	ΔE^*_{ab}
Green	10^{-7} 10^{-6} 10^{-5}	.004 .009 .089
Dblue	10^{-7} 10^{-6} 10^{-5}	.018 .036 .4
Red	10^{-7} 10^{-6} 10^{-5}	.1 .2 1.9

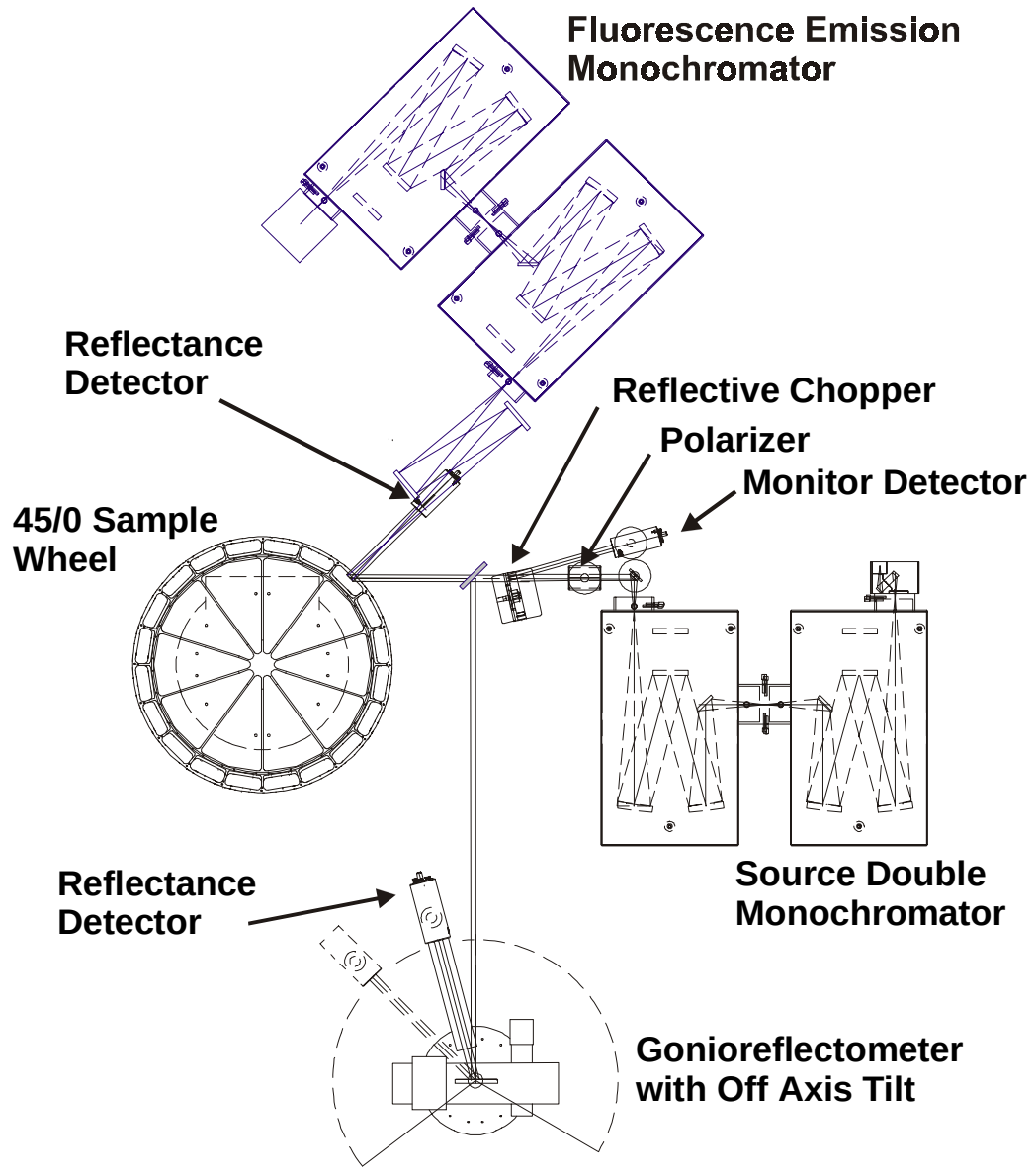
Color Tile	Wavelentgh Uncertainty (nm)	ΔE^*_{ab}
Green	0.05 0.1 0.5	0.049 0.098 0.48
Dblue	0.05 0.1 0.5	0.033 0.065 0.33
Red	0.05 0.1 0.5	0.052 0.1 0.52

Sensitivity Analysis for Instrument Design in Terms of ΔE^*_{ab}

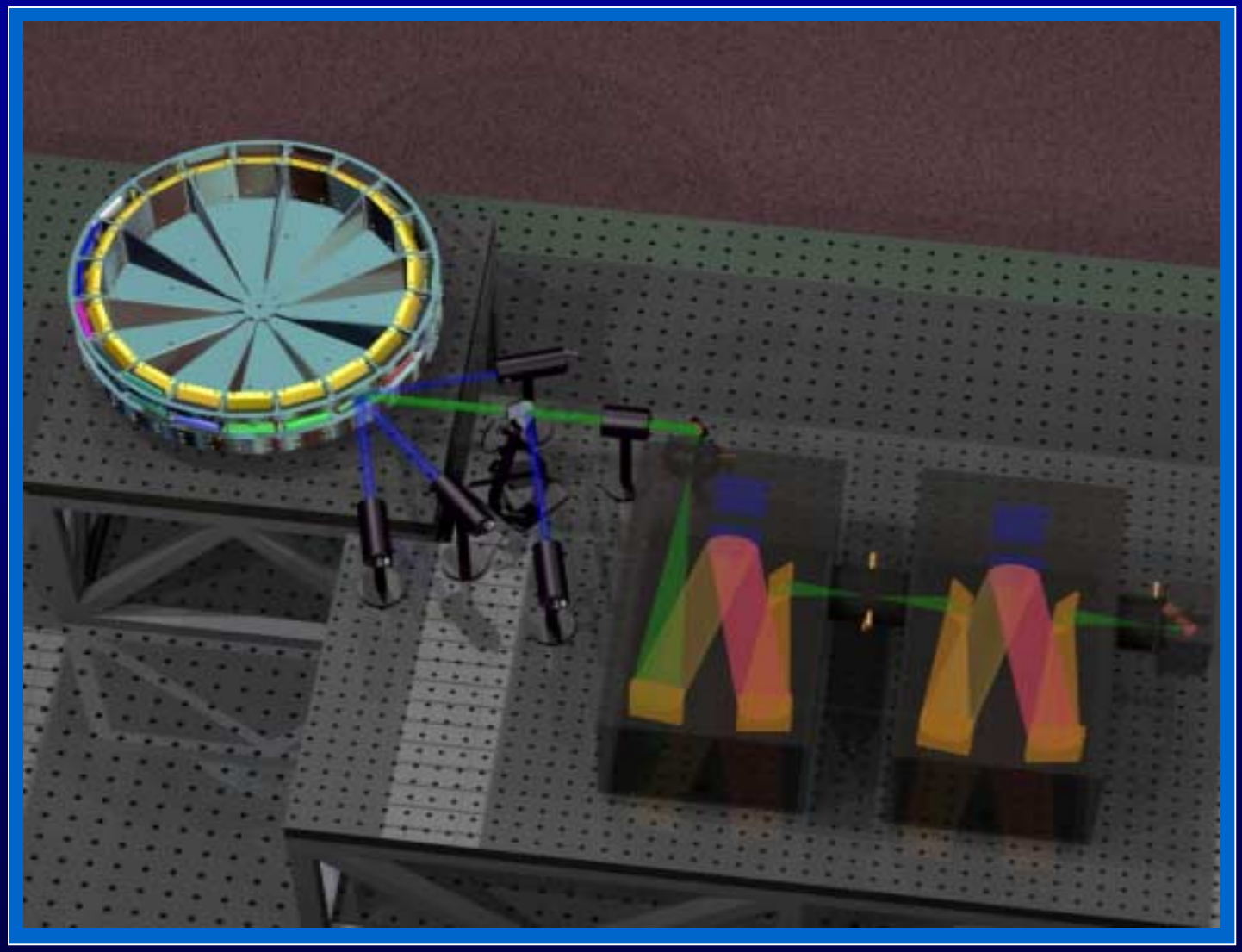
Uncertainty Component	Sensitivity Analysis	ΔE^*_{ab}
Stray light	5×10^{-7}	<0.1
Bandpass	5-8nm	<0.1
Wavelength accuracy	0.1nm	<0.1
Random noise	0.05 %	<0.1
Reflectance scale*	0.4%	<0.2

*Primary white diffuser standards from STARR overall uncertainty (*k*=2) of 0.4%.

NIST Reference Colorimeter



45°/0° Reflectance Colorimeter



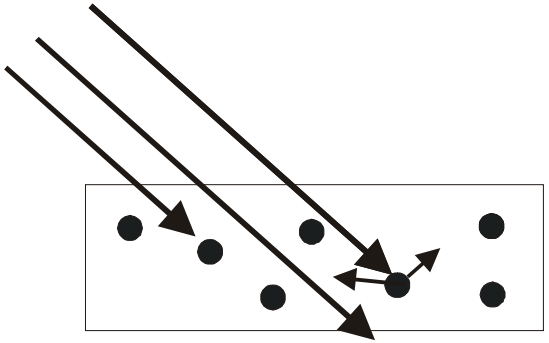
Summary
- Reflectance Colorimetry -

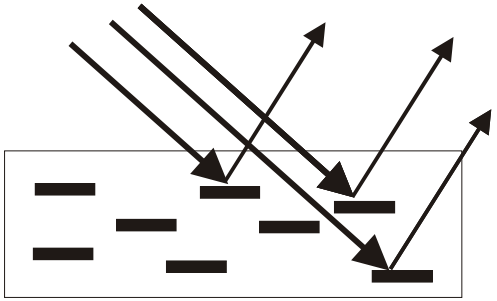
- MAP serves as a diagnostic tool for measurement problems
  - Color standards and measurement parameters / open discussion
- 45°/0° reference reflectance colorimeter

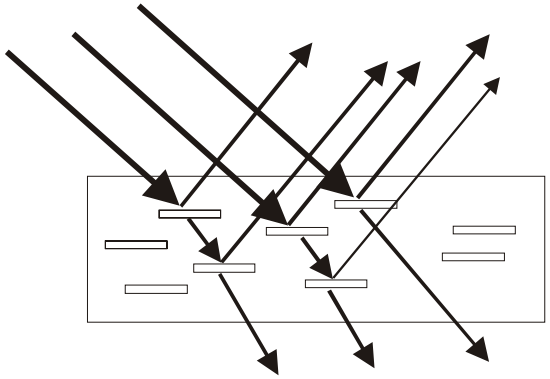
Interference (Pearlescent) Pigments

- Goal: Develop standard test protocol for the characterization of interference pigments
- Color is a result of light interference not light absorption - Appearance depends on the illumination and viewing angle
- Applications: Paints, Plastics, Printing, Cosmetics
- Production and quality control
- Funded by the NIST ATP Motor Vehicle Manufacturing Technology Program

Optical Principle of Pigments







Absorption pigments:

- Diffuse scattering (TiO_2)
- Color is independent of geometry
- Geometry 45°/0° or ~0°/d
- CIE and ASTM

Metallic pigments:

- Metal-flake (Al) pigments in a clear resin, like mirrors
- Color depends on the viewing angle
- Geometry 45°/15° & 45° & 110°
- ASTM

Pearlescent pigments:

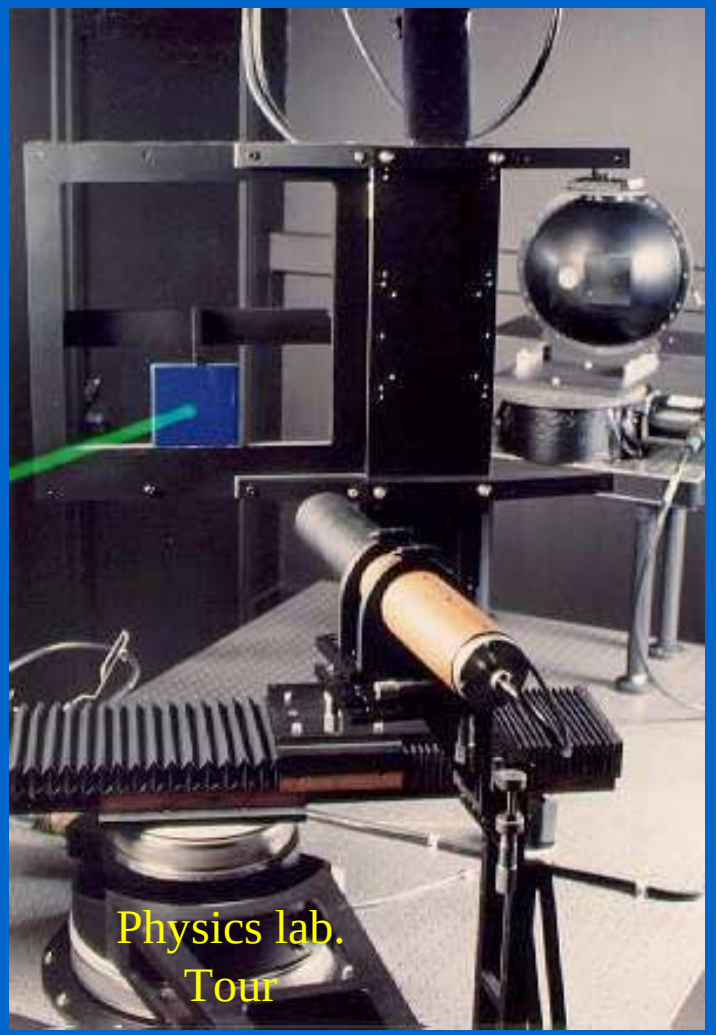
- Small, thin platelet of transparent material (mica coated with TiO_2 (n=2.4)), thin-film interference
- Color depends on the illumination and viewing angle
- Geometry under study (ASTM)

Measurement Protocols

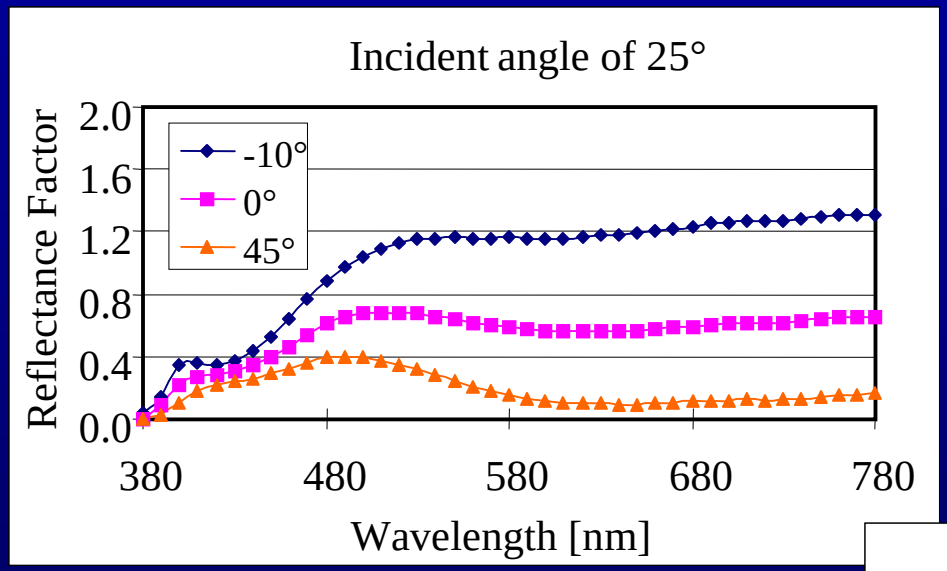
- Specular scan
  - λ = 380 nm to 780 nm at 10 nm steps
  - θ_i = 10° to 70° at 10° step
  - θ_v = ± 16° with respect to specular component
- Extension of metallic measurement protocol
  - λ = 380 nm to 780 nm at 10 nm steps
  - θ_i = 25°, 45°, and 60°
  - θ_v = specular, normal, aspecular angles (15°, ~100°) component
- Samples (ASTM E12 - Du Pont and Flex Products)
  - Green and medium light ruby pearlescent
  - Silver/Green pearlescent

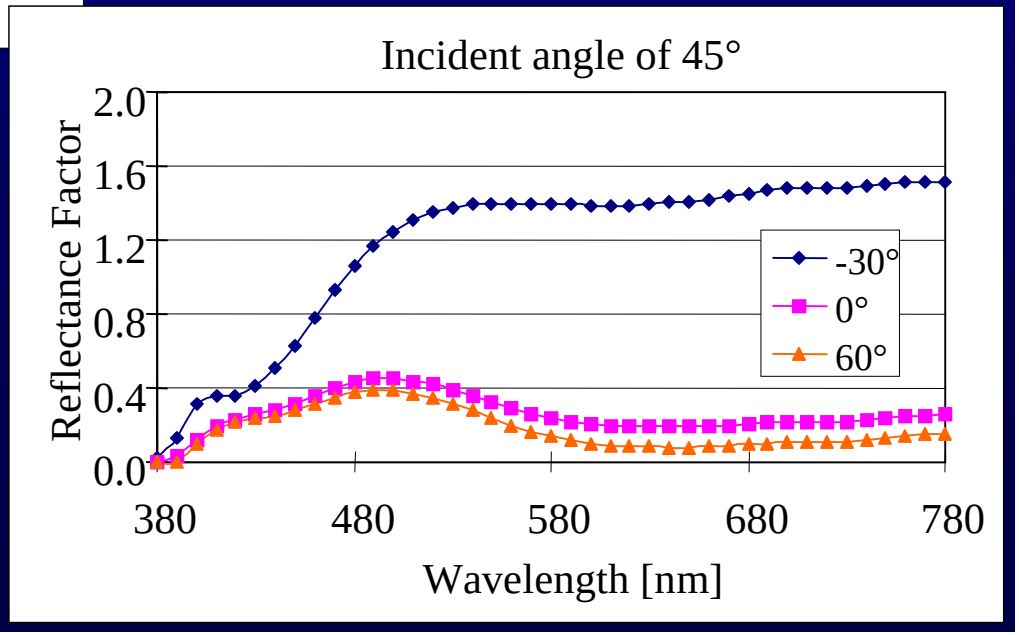
Optical Reflectance Measurements

- Spectral Tri-function Automated Reference Reflectometer (STARR)
  - collimated, monochromatic, polarized beam of light (250nm - 2500nm)
  - mono-plane goniometer: sample and detector
  - absolute measurements of bidirectional and directional-hemispherical reflectance
  - relative combined expanded uncertainty (k=2): 0.4%

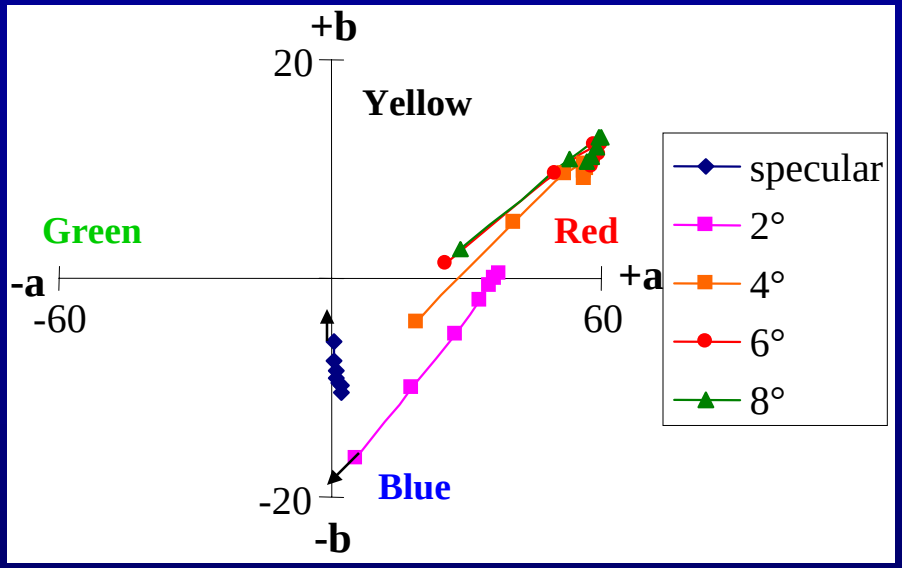


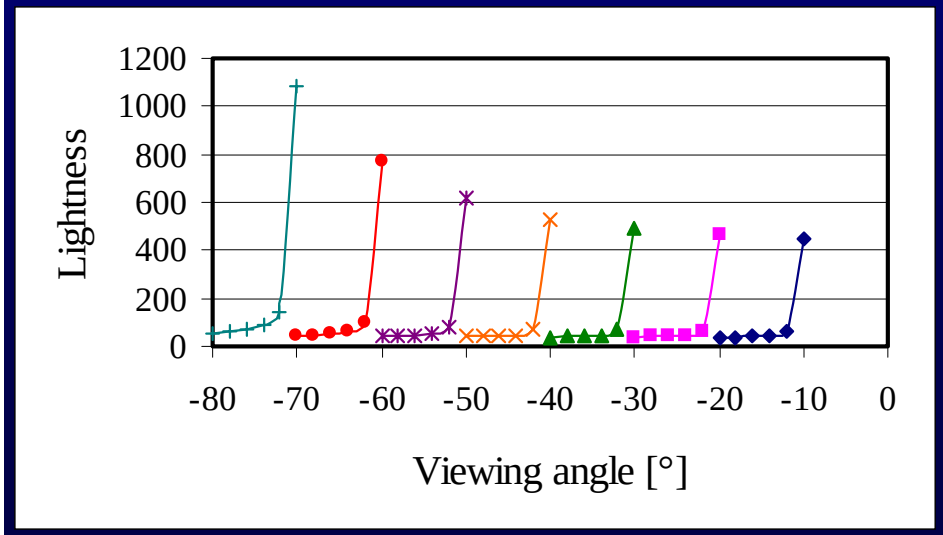
Reflectance of Green Pearlescent Sample

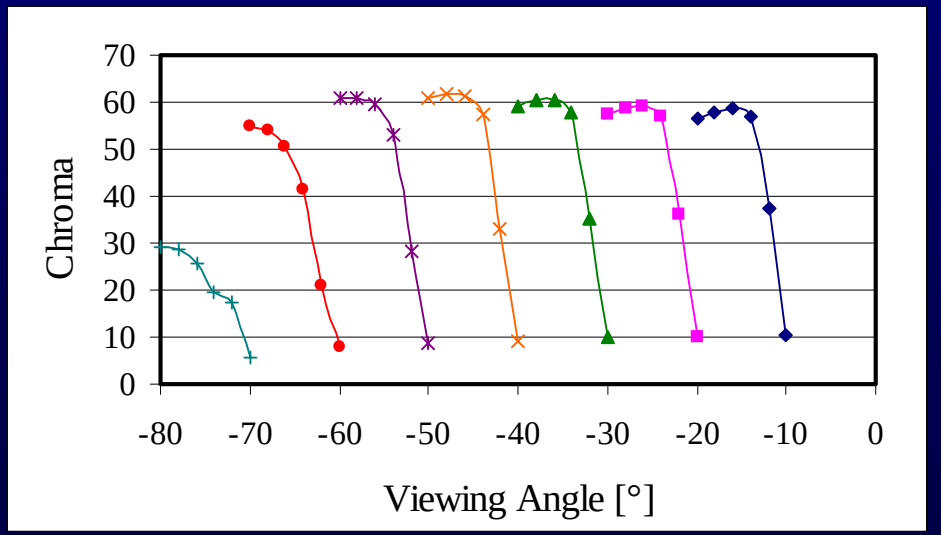




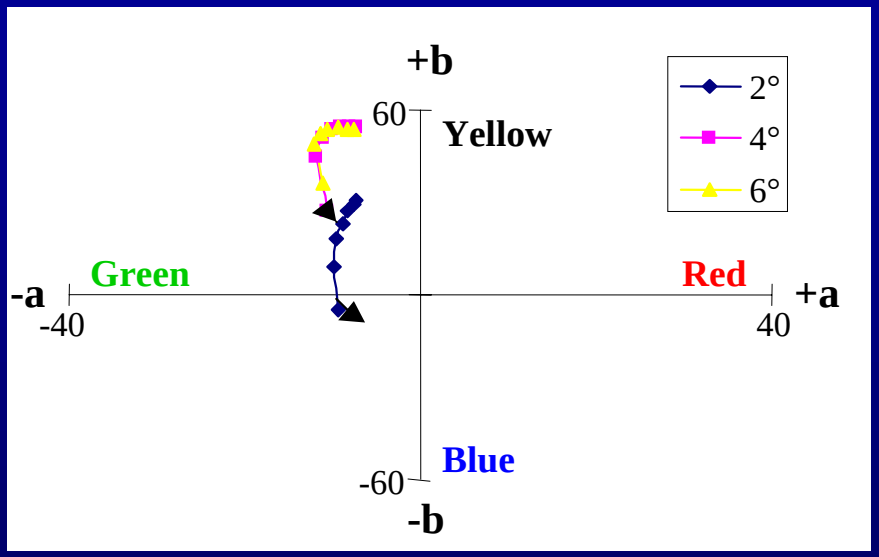
Colorimetry for Red Ruby Pearlescent

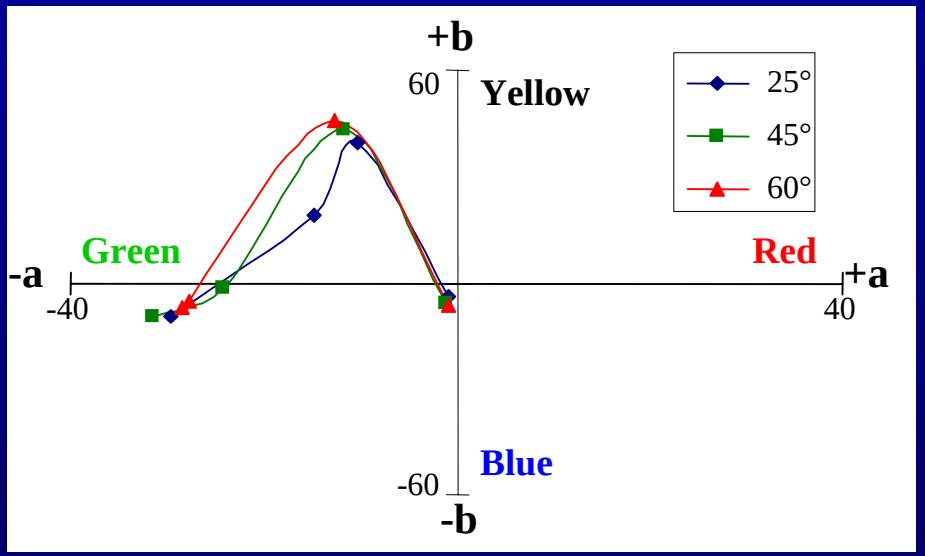


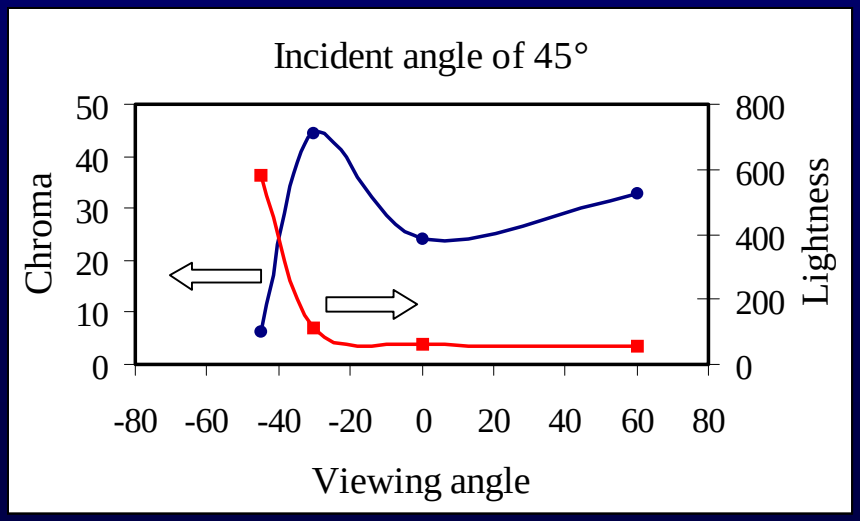


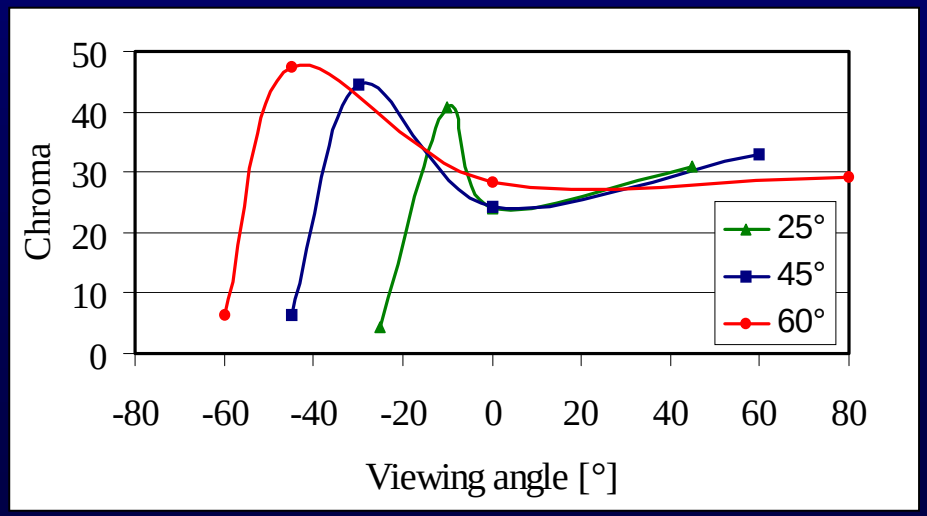


Colorimetry of Green Pearlescent Sample









Future Directions

- Specular Gloss
  - Special test calibration
  - Image formation
- Reflectance Colorimetry
  - Characterize instrument and establish MAP for 45°/0°
- Interference Pigments
  - Control samples
  - Collaboration with microstructure characterization