Sources for figures

- Greg J. Ward, Measuring and modeling anisotropic reflection, Proc. Siggraph '92.
- Eugene Hecht, Optics, second edition, Addison-Wesley, 1987.
- Rasheed M.A. Azzam, Ellipsometry, in Handbook of Optics, M. Bass ed., McGraw-Hill, 1995, vol. II, section 27.
- Gunter Wyszecki and W.S. Stiles, Color science: concepts and methods, quantitative data and formulae, second edition, Wiley, 1982.
- Ross McCluney, Introduction to radiometry and photometry, Artech House, 1994.

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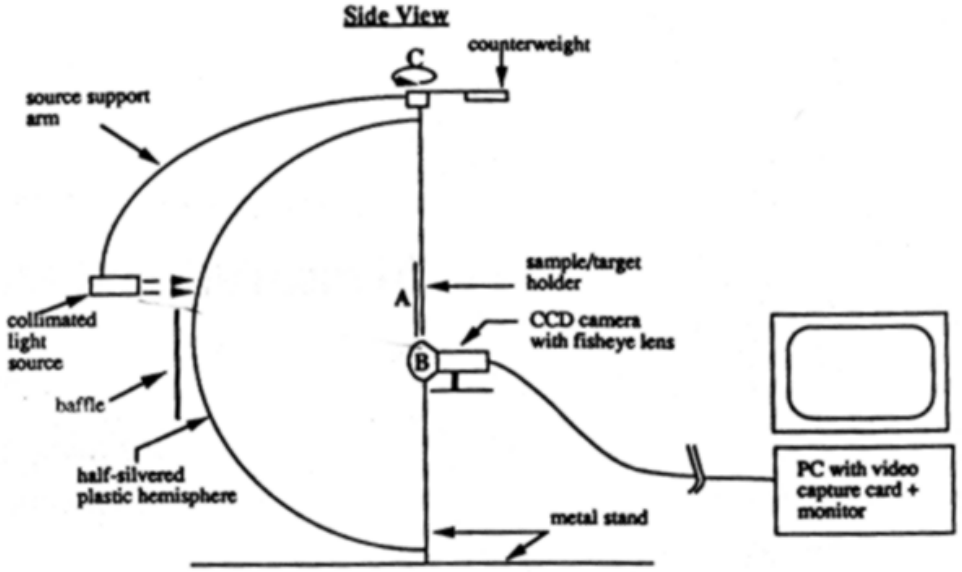
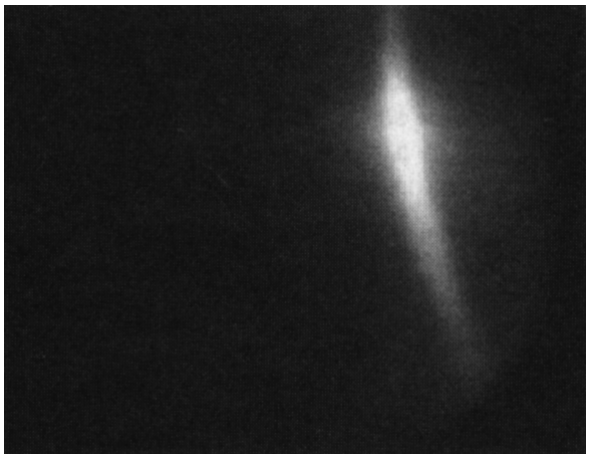
Ward's point-to-sphere imaging gonioreflectometer (1D, 1D, 2D scanned)





(Ward, figures 2 and 4)

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A sphere-to-sphere dual imaging gonioreflectometer? (2D scanned, fixed, 2D scanned)

- hand-held
- no moving parts
- modifiable for spatially varying BRDF

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Other devices

- glossimeters
  - specular gloss
  - sheen
  - luster
  - bloom
  - distinctness
- haze meters
- nephelometer
- turbidimeter
- etc.

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How much BRDF data is enough? (for computer graphics)

- Where is the detail in a 7D BRDF?
  - specular highlights
  - grazing angles
  - spatial variation
  - unusual materials
- 7D prefiltering (to avoid aliasing)
  - illumination angle — light aperture
  - reflection angle — camera aperture
  - spatial variation — pixel size*
  - spectral variation — light SPDs

*integrates across angles too unless collimated light and parallel camera view

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Example

- Cornell system
  - 40^3 = 64,000 samples for isotropic surface
  - 10 degree increments, more near specular
  - 1 sample / 2 seconds = 8 hours
  - fit to approximation of He model (1991)
- What are they missing?
  - spectral variation?
  - anisotropic surfaces
  - spatial variation

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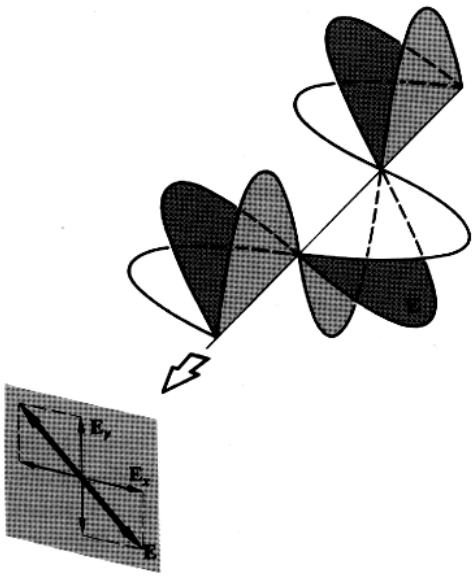
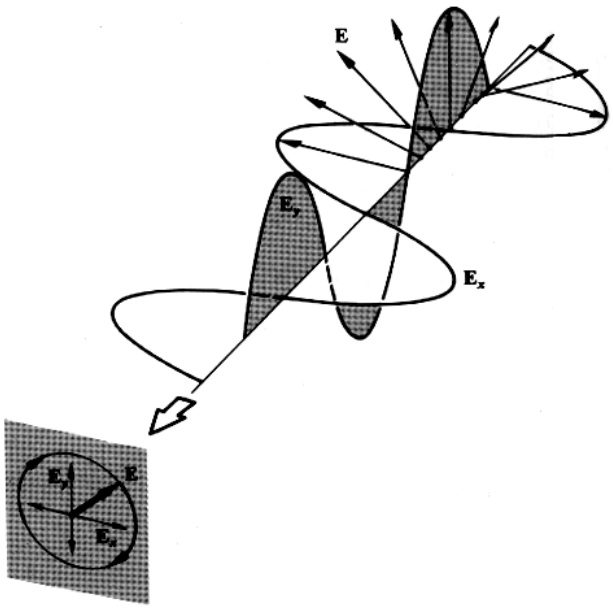
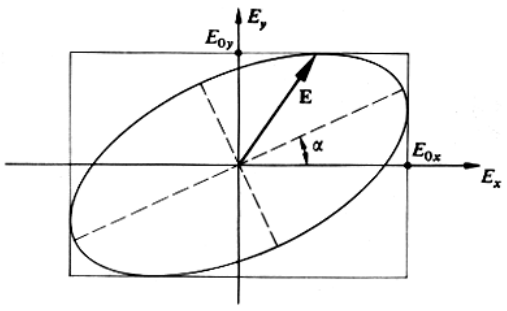
Polarized light



linearly polarized



circularly polarized



elliptical

(from Hecht)

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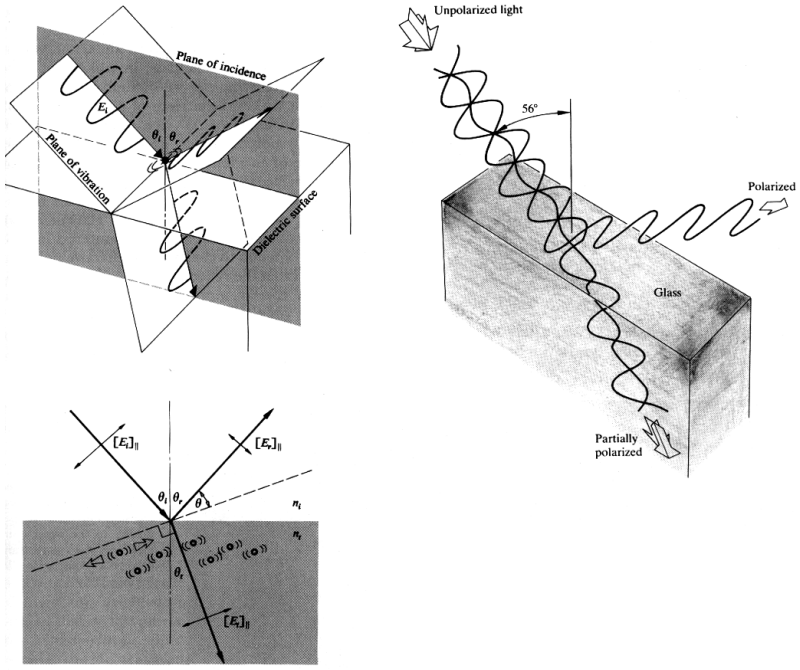
Polarization and reflection



- nonconductors (dielectrics)
  - unpolarized illumination → partially polarized reflection
  - at Brewster angle θ, reflection is completely polarized
- conductors (metals)
  - same, but reflection not completely polarized

(from Hecht)

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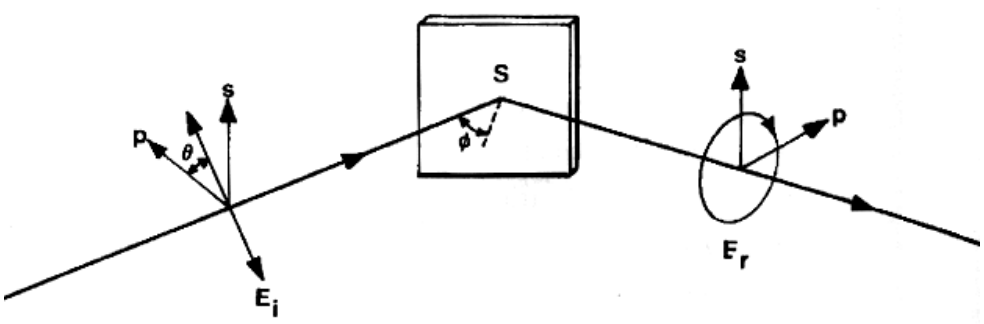
Polarization and isotropy



- isotropic surfaces
  - p-illumination → attenuated p-reflection
  - s-illumination → attenuated s-reflection
  - illumination E_i linearly polarized at azimuth θ → attenuated reflection linearly polarized at θ + Δ
  - 2 measurements are necessary
    - » illuminate with p, measure p
    - » illuminate with s, measure s

$$E_{rp} = R_p E_{ip} \qquad E_{rs} = R_s E_{is}$$

  - each reflection is 2 (complex) multiplies

(from Azzam)

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- smooth anisotropic surfaces
  - linearly polarized illumination → elliptically polarized reflection
  - 4 measurements are necessary
    - » illuminate with p, measure p and s
    - » illuminate with s, measure p and s

$$\begin{bmatrix} E_{rp} \\ E_{rs} \end{bmatrix} = \begin{bmatrix} R_{pp} & R_{ps} \\ R_{sp} & R_{ss} \end{bmatrix} \begin{bmatrix} E_{ip} \\ E_{is} \end{bmatrix} \qquad \text{(Jones matrix)}$$

  - each reflection is a 2 x 2 (complex) transformation

- rough anisotropic surfaces
  - linearly polarized illumination → partially elliptically polarized reflection
  - 16 measurements are necessary

$$\mathbf{S}' = \mathbf{MS} \qquad \text{(Mueller matrix)}$$

    where **M** is a 4 x 4 real matrix

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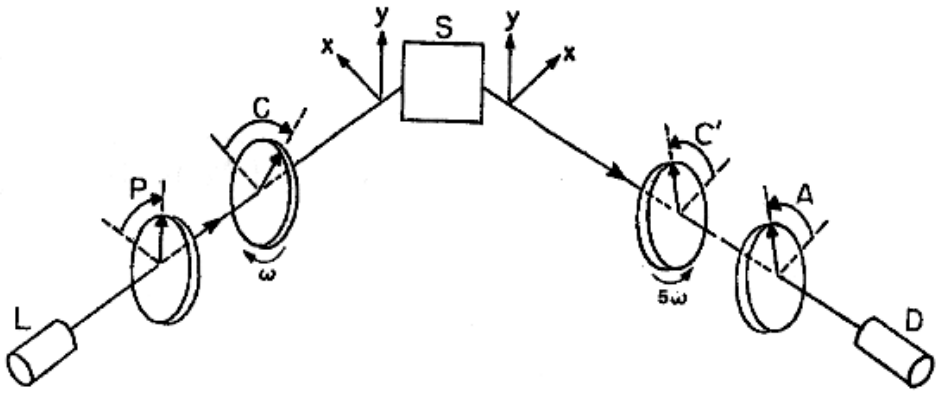
Measuring polarization

- rough anisotropic surfaces
  - Mueller-matrix photopolarimeter
  - light → polarizer → retarder → sample → retarder → polarizer → detector
  - requires collimated monochromatic light



- smooth anisotropic surfaces
  - omit retarders
  - light need not be monochromatic

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How important is polarization? (for computer graphics)

- single bounce rendering
  - not important, because the eye is not sensitive to polarization
- multi-bounce / global illumination
  - important
- common polarization situations
  - glare from sun on water
    - » only important on second bounce
  - scattering from a clear sky
    - » how important if integrated over hemisphere?
  - scattering from cloudy sky
    - » probably nearly unpolarized

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Spectral measurement devices

- colorimeters
  - filter
  - template
- monochromators
  - prism
  - grating
- spectroradiometers
  - spectroradiometer
  - spectrophotometer

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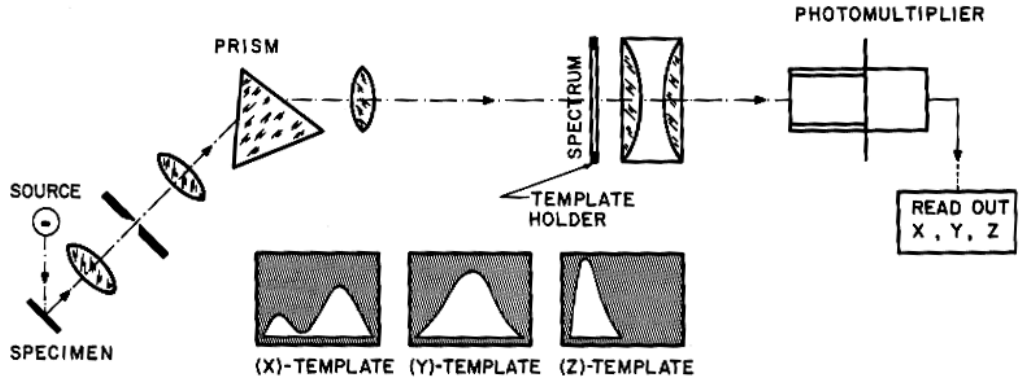
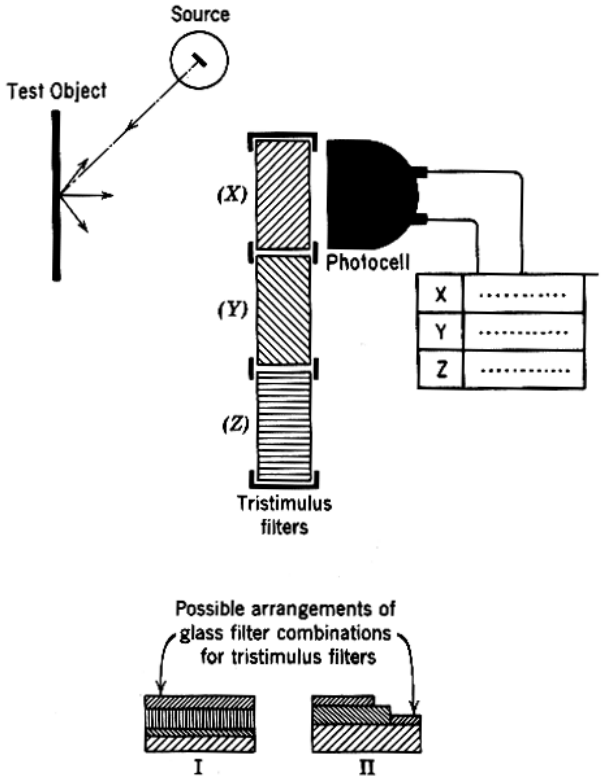
Colorimeters



template colorimeter



filter colorimeter

(from Wyszecki and Stiles)

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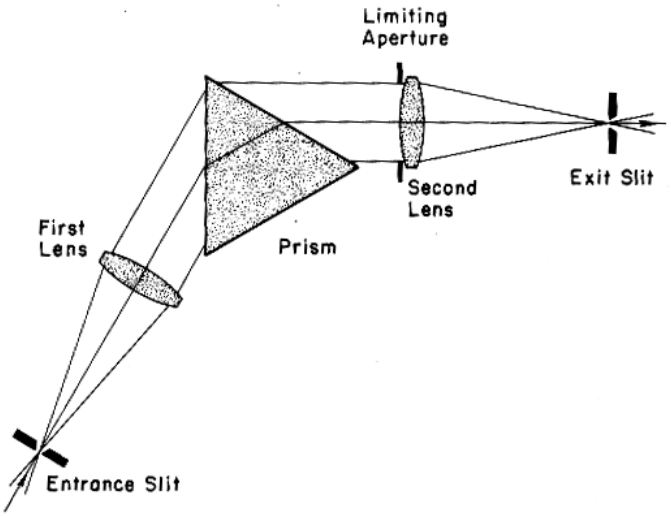
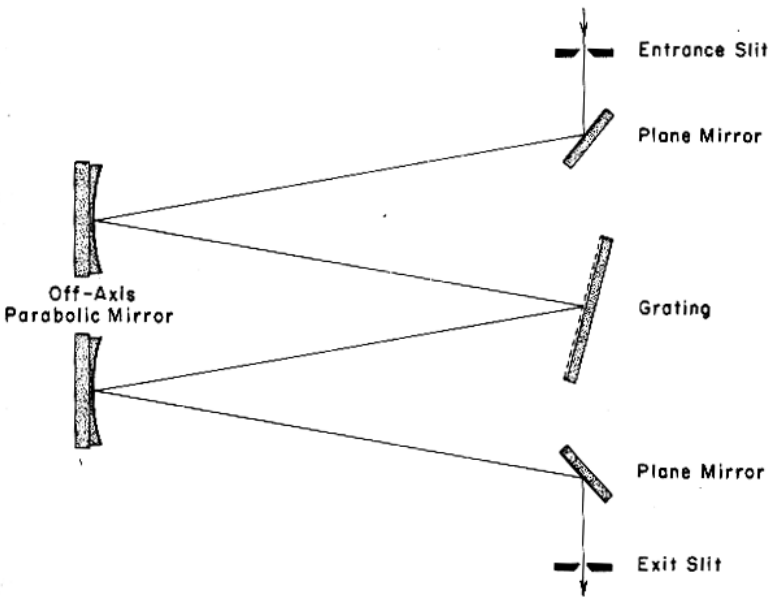
Monochromators



single-prism monochromator



Ebert-type grating monochromator

(from Wyszecki and Stiles)

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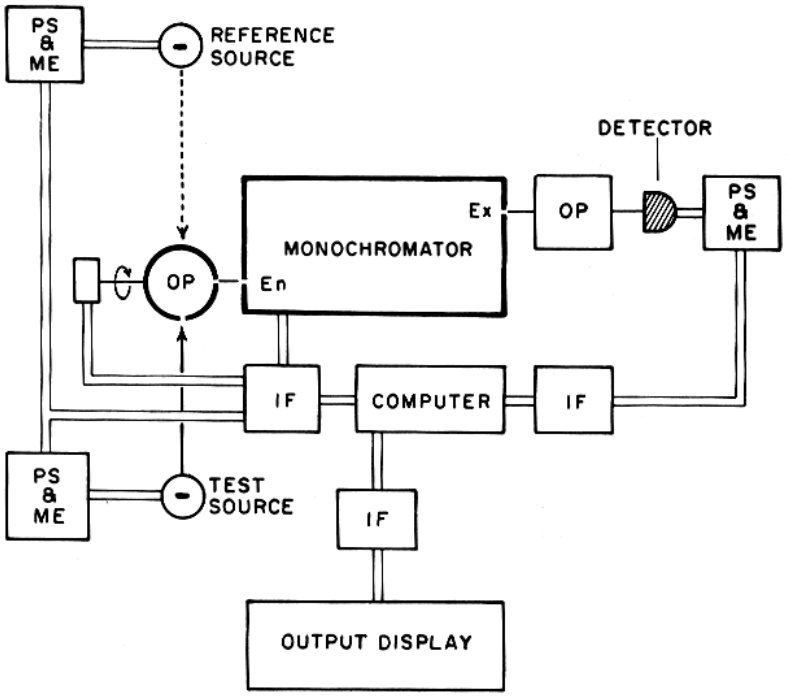
Spectroradiometer



(from Wyszecki and Stiles)

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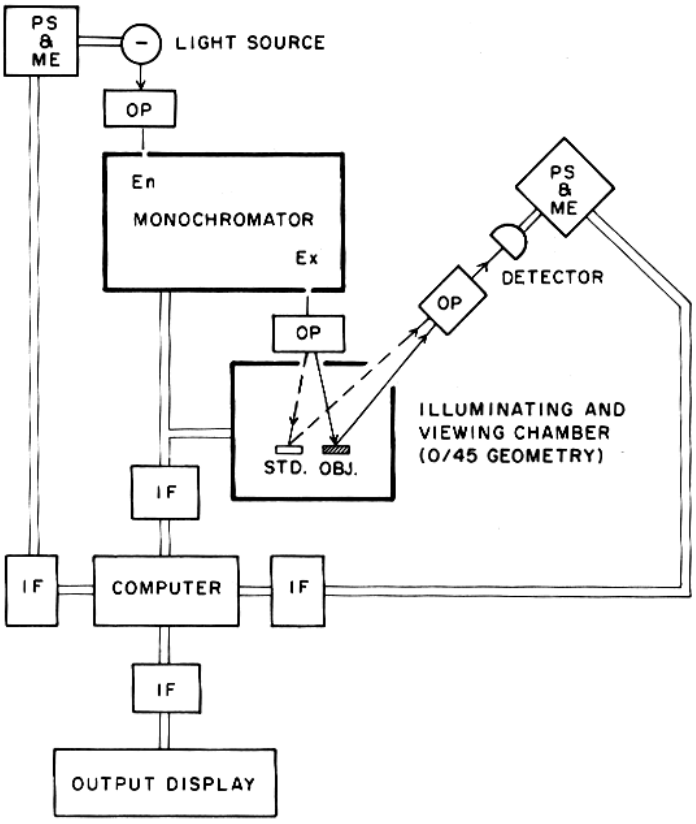
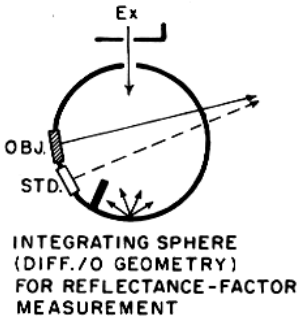
Spectrophotometer (spectro-photo-reflectometer)



typical viewing chamber:



(from Wyszecki and Stiles)

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How much spectral characterization is enough? (for computer graphics)

- RGB, broadband light source
  - reflections wrong if rendering light differs
- RGB, light source = rendering light
  - first reflection correct
  - subsequent reflections wrong
  - 3 x 3 matrix better than 3 multiplies (Peercy, 1993)
- better solutions
  - basis functions, usually > 3
  - many samples, e.g. 30 x 10nm

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