The appearance of manufactured materials

- milling, finishing
  - anisotropic reflection models (Kajiya, 1985), (Poulin and Fournier, 1990), (Ward, 1993)
- painting, lacquering
  - scattering in diffuse laminar materials (Kubelka-Munk, 1931)
  - subsurface light transport (Hanrahan and Krueger, 1993)
- weathering, patination
  - layers and operators on them (Dorsey and Hanrahan, 1996)
    - » coat, erode, fill, polish, offset
- erosion, deposition, staining
  - flow of water across a surface (Dorsey, Pederson, and Hanrahan, 1996)

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Measurement devices

- simple detectors
  - measuring radiance and irradiance
  - radiometers versus photometers
- goniometric characterization
  - integrating spheres
  - gonioreflectometers and goniotransmittometers
  - glossimeters, hazemeters, and other exotica
- polarization characterization
  - polarimeters
- spectral characterization
  - monochromators
  - colorimeters
  - spectroradiometers and spectrophotometers

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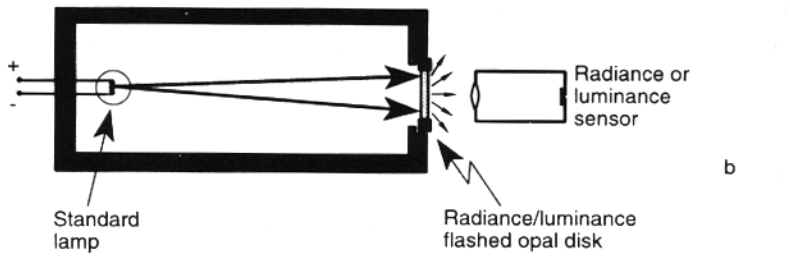
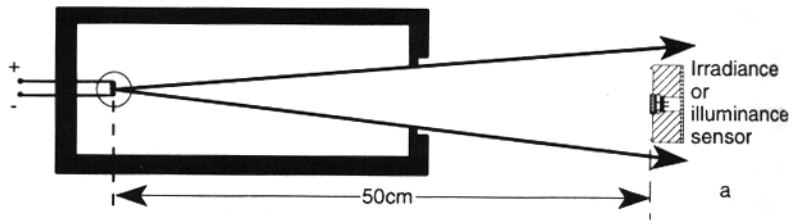
Measuring radiance and irradiance



measuring the light leaving a surface (radiance)

$$L(\omega) \qquad \left[\frac{W}{m^2\, sr}\right]$$



measuring the light incident on a surface (irradiance)

$$E(\omega) = \int_{2\pi} L(\omega)\cos\theta\, d\omega \qquad \left[\frac{W}{m^2}\right]$$

(from McCluney)

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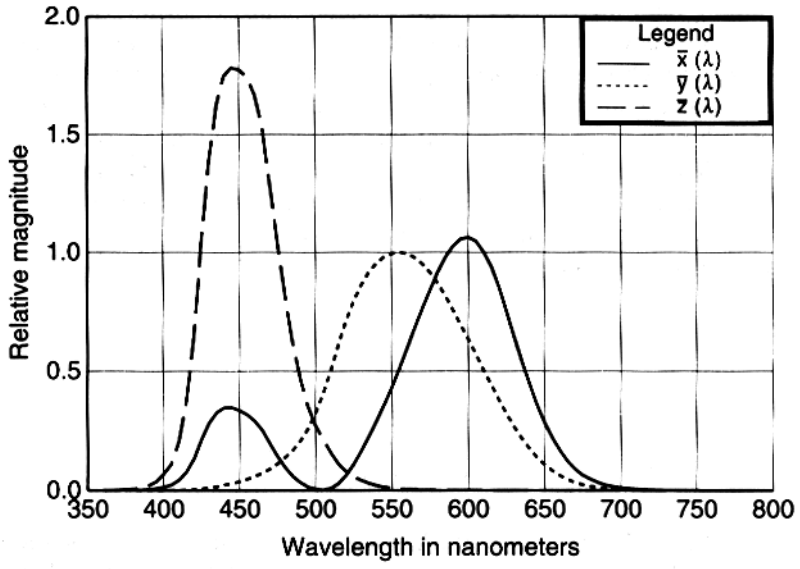
Radiometers versus photometers



$$L_v = 683 \int_{380}^{770} L_\lambda \; V(\lambda)\, d\lambda \qquad \left[\frac{lm}{m^2\, sr}\right]$$

$$V(\lambda) = \bar{y}(\lambda)$$

(from McCluney)

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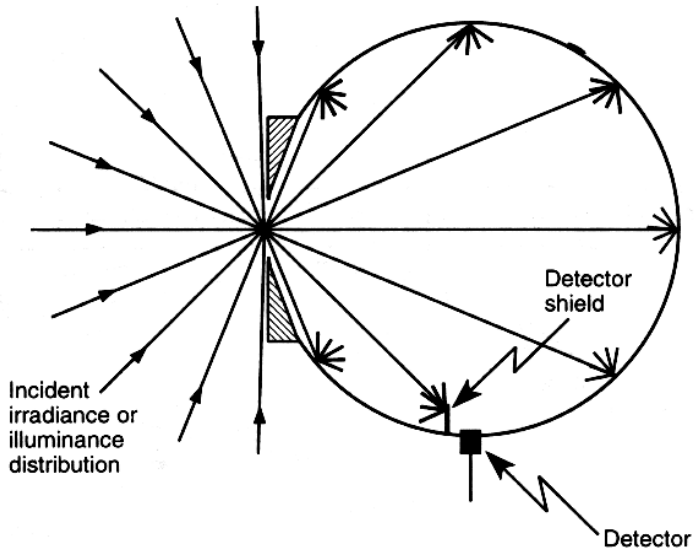
Measuring irradiance using an integrating sphere

$$F_{A_i A_j} = \frac{1}{A_i} \iint_{A_i \; A_j} \frac{\cos\theta_i \; \cos\theta_j}{\pi \; r^2} \; dA_j \; dA_i$$

The form factor between any two patches on the inside surface of a sphere is the same.



The response to an incident irradiance at any angle will be the same.

(from McCluney)

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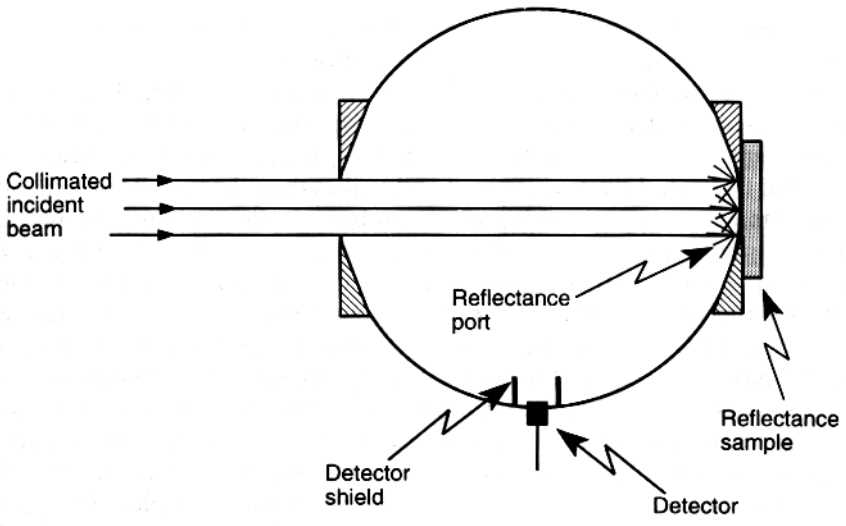
Measuring total integrated reflectance

$$\rho(\omega_i \rightarrow 2\pi) = \int_{2\pi} f_r\,(\omega_i \rightarrow \omega_r)\cos\theta_r\; d\omega_r$$

directional-hemispherical reflectance



measurement using an integrating sphere

(from McCluney)

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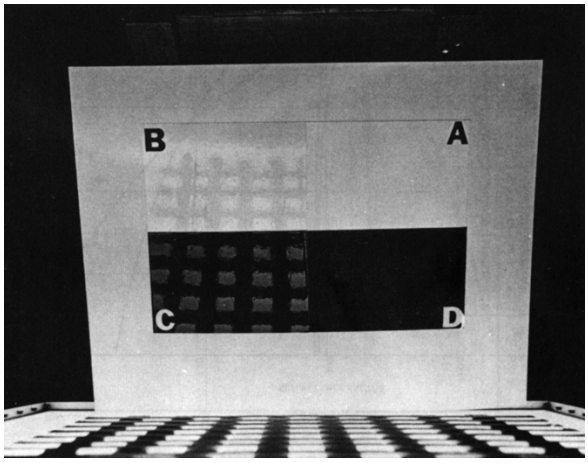
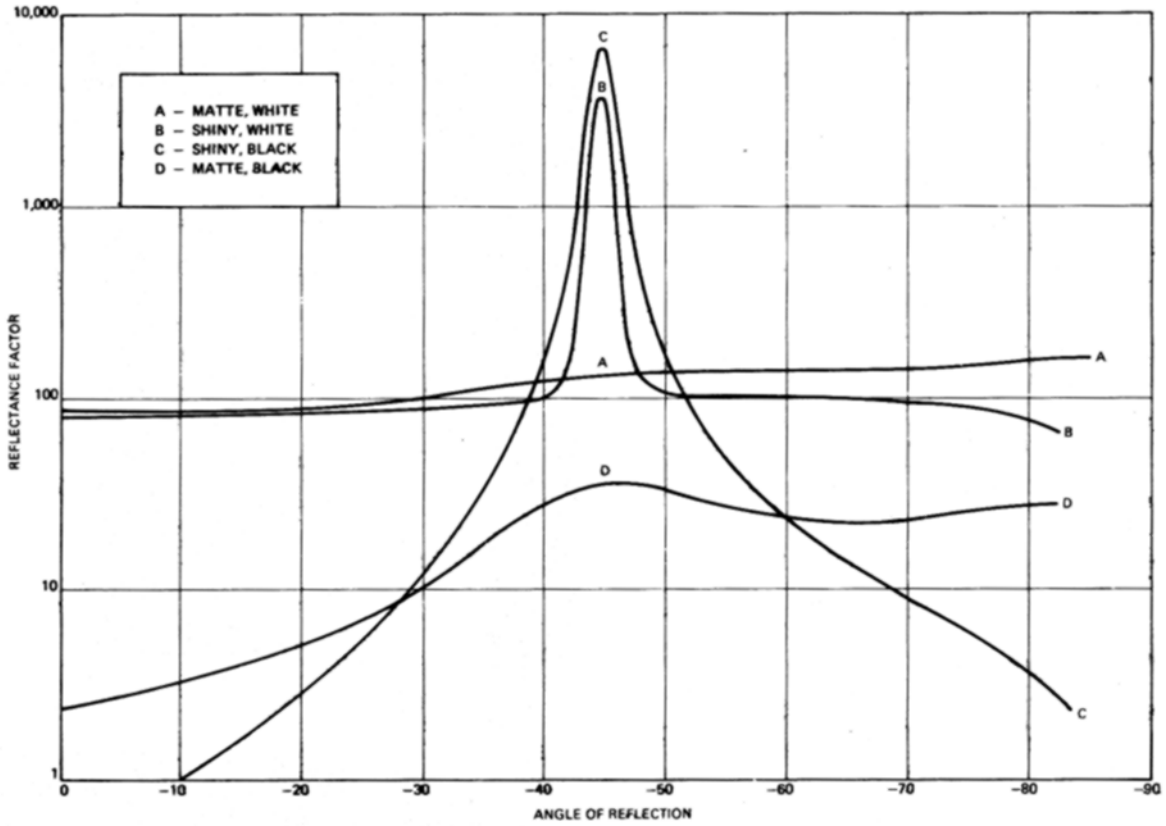
Examples of specular and total reflectance





four paper samples

(from Hunter)

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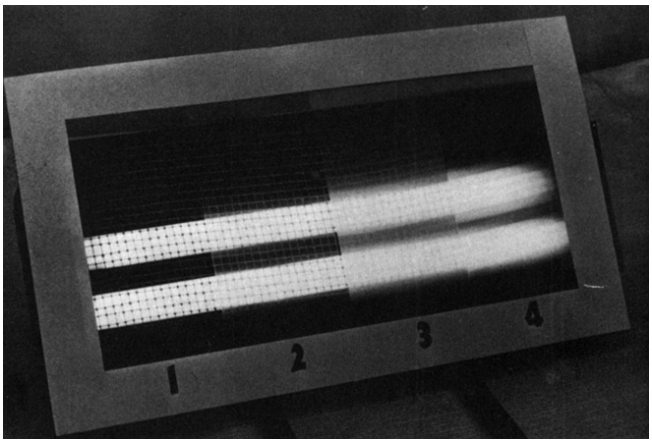
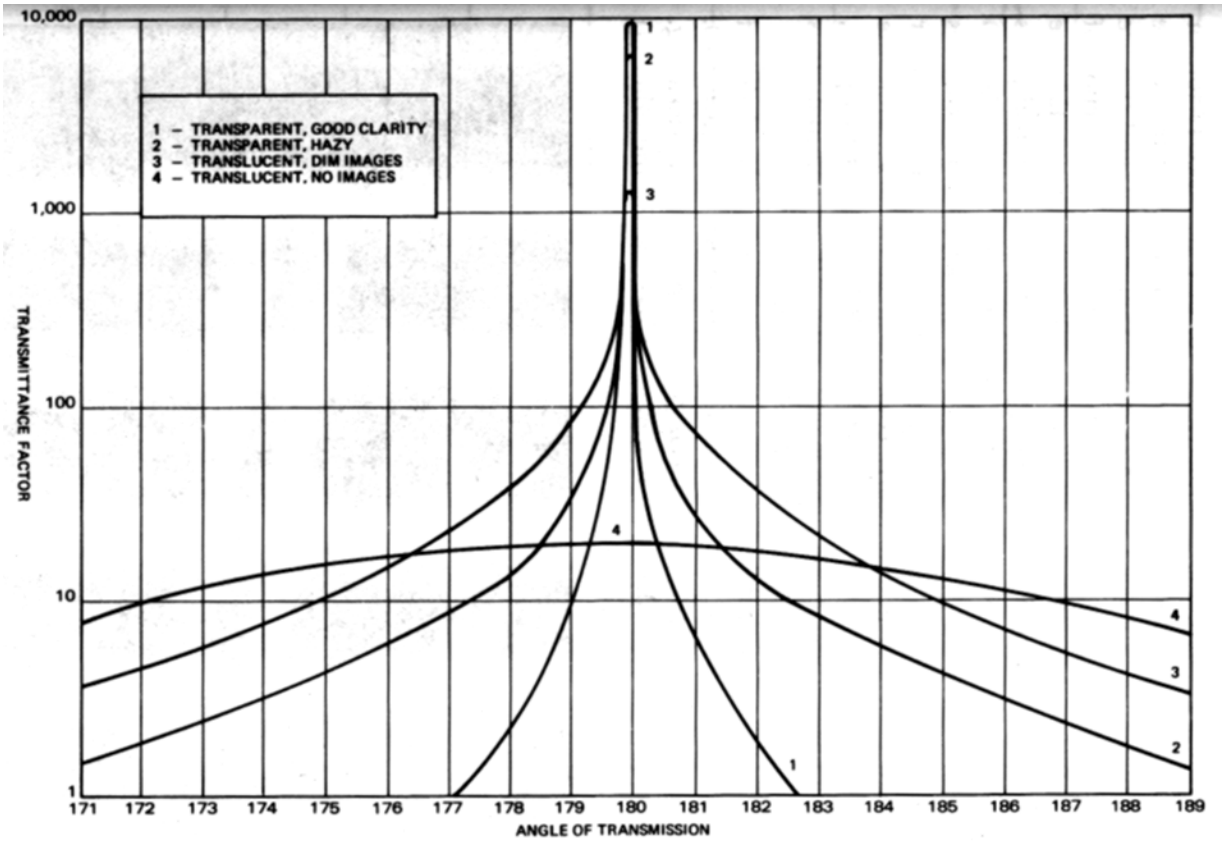
Examples of clarity of specular transmission





1 degree

four plastic sheets

(from Hunter)

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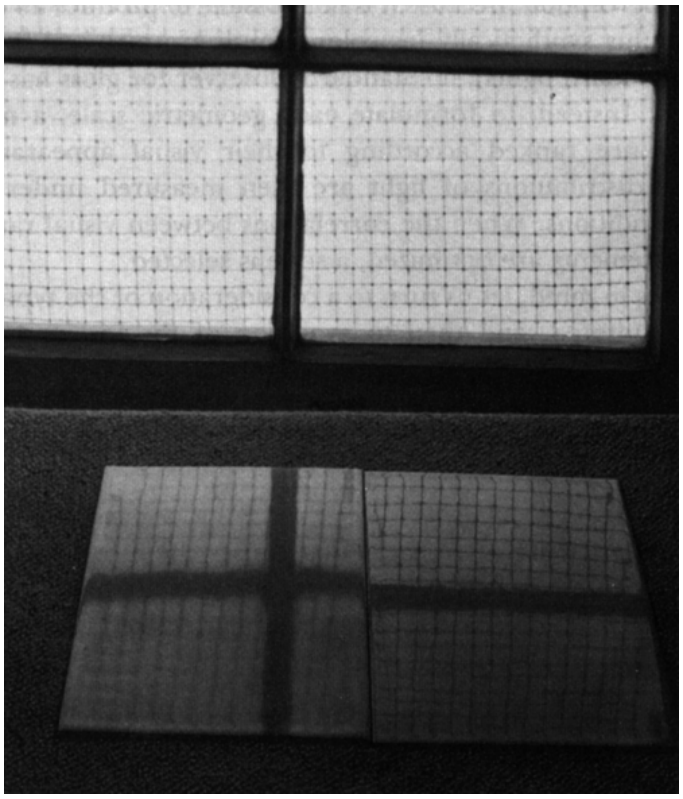
Examples of clarity of specular reflection



white porcelain enameled panels
specular reflections differ only in innermost 0.5 degree

(from Hunter)

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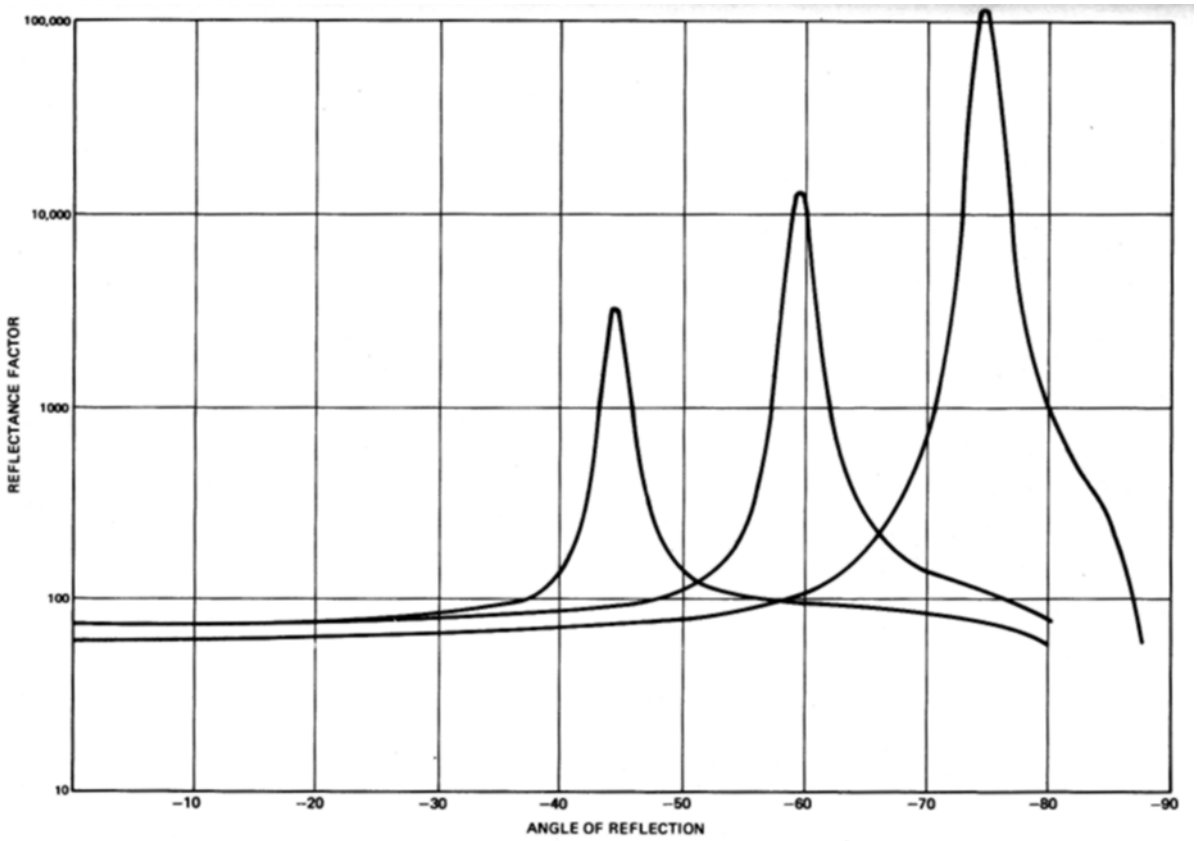
Examples of reflectance for different angles of incidence



paper sample
light incident at 45, 60, and 75 degrees

(from Hunter)

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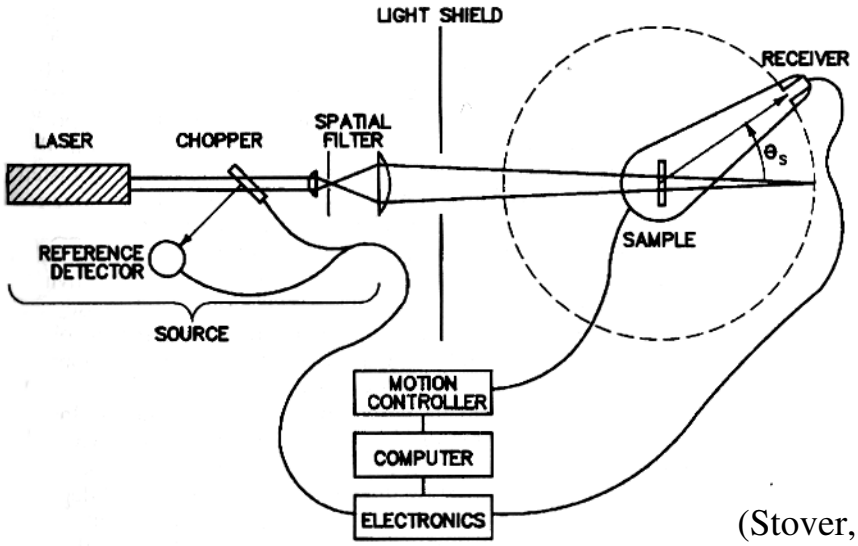
Typical scatterometer (BRDF + BTDF = BSDF)



(Stover, fig 2)

- geometric design
  - point versus line versus area source & detector
  - fixed versus moving DOFs
  - motorized versus manual
  - stop-motion versus on-the-fly
- other issues
  - coherent vrs. incoherent illumination
  - collimated versus converging beam
  - dynamic range: 12 orders of magnitude
  - linearity, noise, other systematic errors

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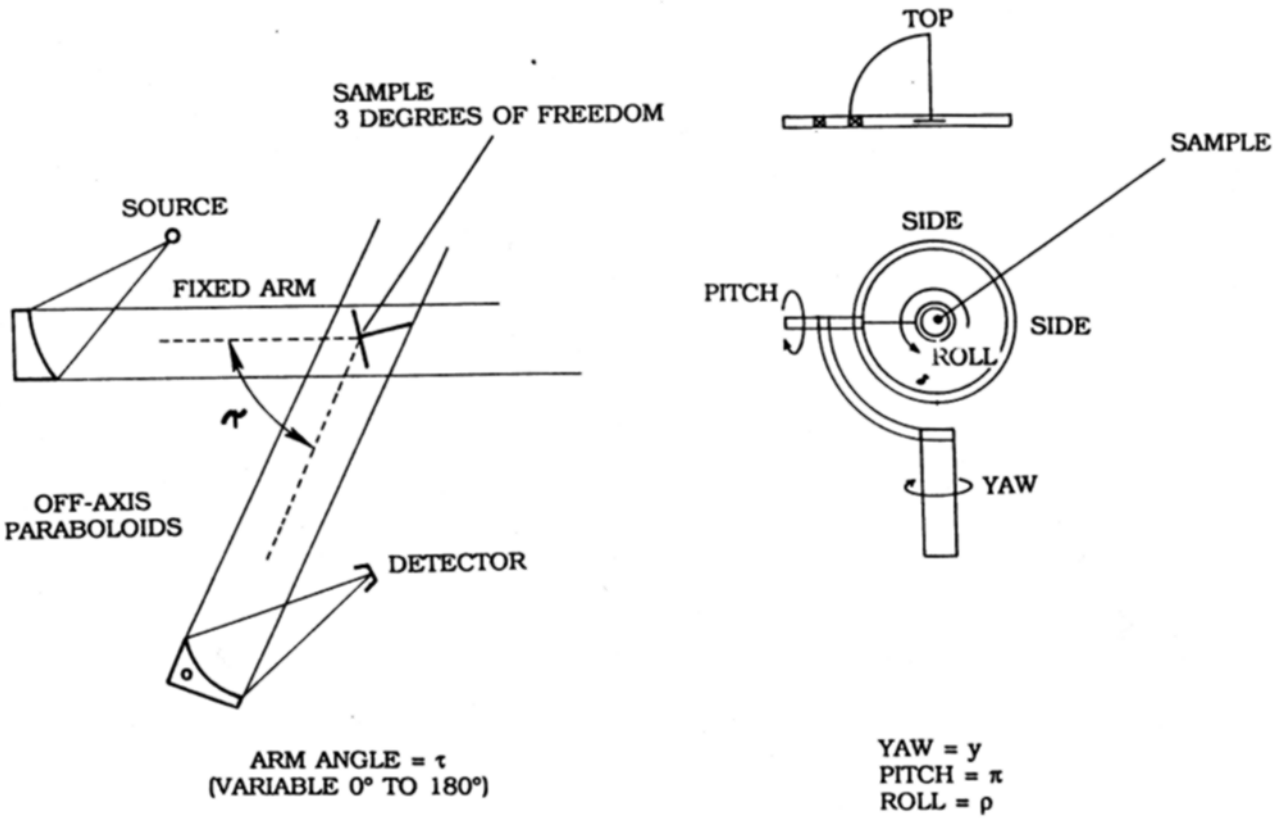
fixed source,
3-DOF sample,
1-DOF detector



(Neu and Bressler, Figure 4)

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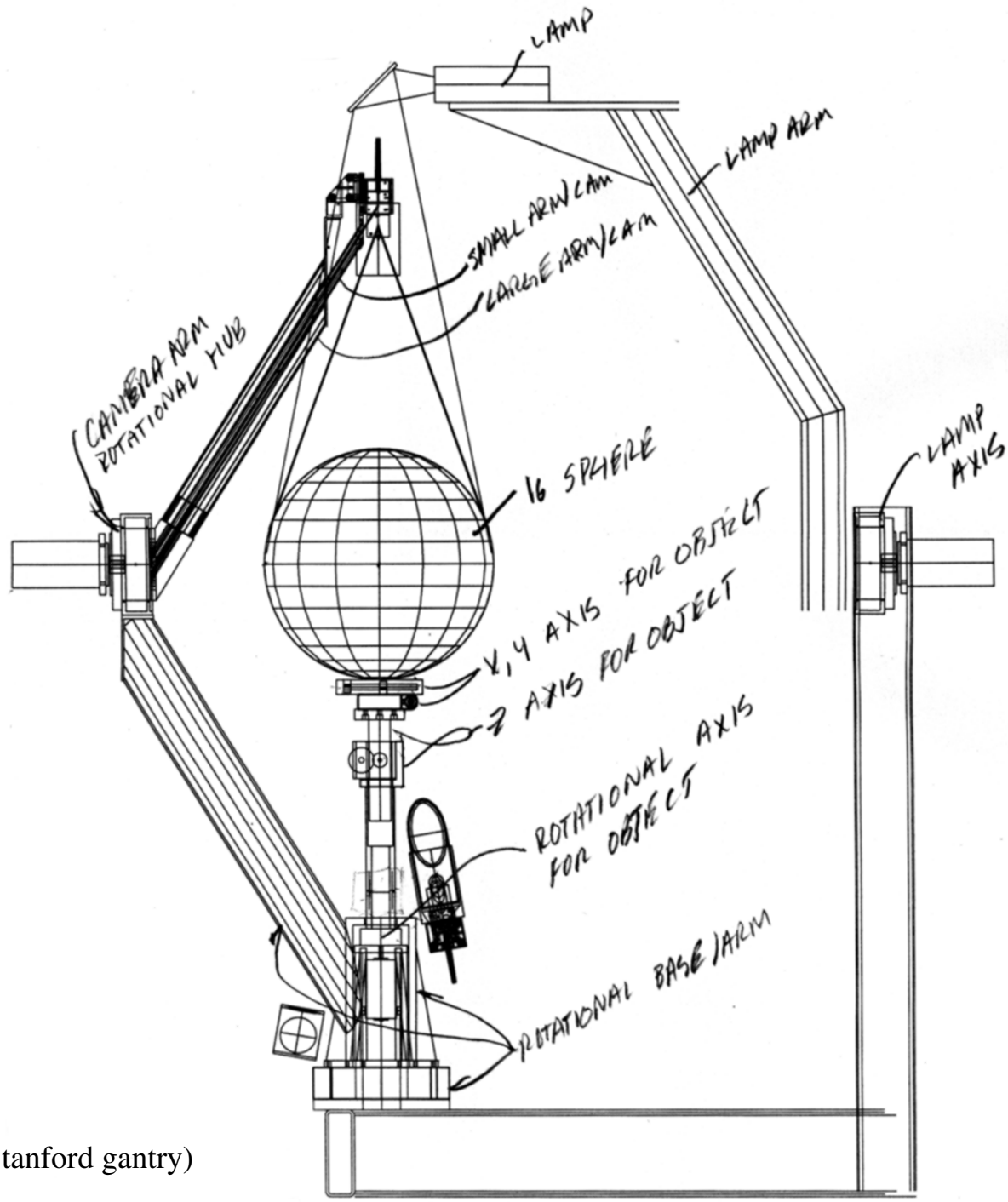
1-DOF source,
1-DOF sample,
2-DOF detector



(Stanford gantry)

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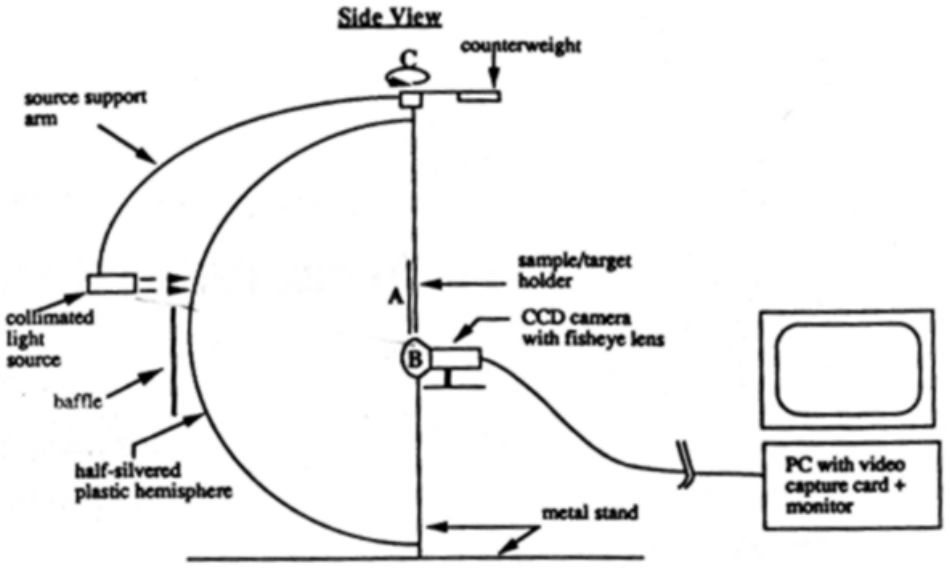
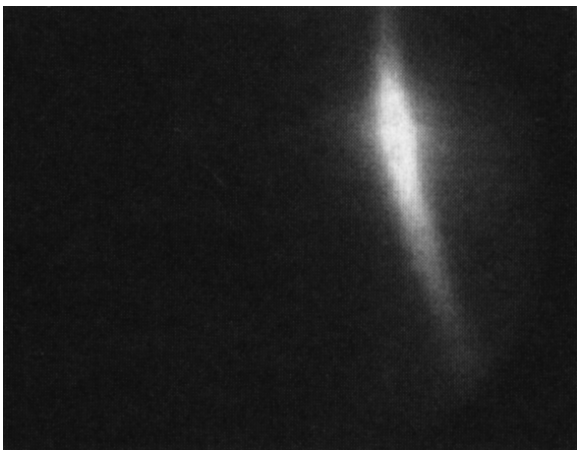
Ward's point-to-sphere imaging gonioreflectometer (1D, 1D, 2D scanned)





(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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