

Einführung in die Farbwissenschaft

Color and Reflectance Measurements



Radiometry vs. Photometry

- **Radiometry** is the science and technology of the measurement of electromagnetic radiation over the whole spectrum of electromagnetic waves
- **Spectroradiometry** concerns itself with the spectral composition of electromagnetic radiation
- **Photometry** and **Spectrophotometry** are the same in terms of the visible spectrum, and the average human observer

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Color Measurements

- important for many applications
 - ◆ textile industry
 - ◆ paper industry
 - ◆ leather industry
 - ◆ graphics arts industry
 - ◆ ...
- not simple
- standardized

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Spectroradiometric Standards

- accurate measurements of optical radiation involve a reference standard in some way
- this can be:
 - ◆ a *source* of known emissivity
 - ◆ a *detector* with an exactly known response
 - ◆ a *surface* with exactly known reflectivity
- 2 basic types of emission standards exist:
blackbodies and **reference lamps**

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Blackbody Standards

- advantage of blackbody radiation:
 - ◆ known spectral power distribution
- problem:
 - ◆ maintaining constant temperature
- basic idea:
 - ◆ during a phase change such as freezing, the phase maintains a constant temperature to within very close tolerances
 - ◆ during its freezing process a given material offers a reliable reference standard for blackbody radiation

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Blackbody Standards

- advantage: potentially very accurate
- disadvantage: except for the infrared portion of the spectrum, a blackbody radiator has to operate at temperatures around at least 2500K
- IR: commercial devices exist
- visible: only used for reference standards in national standards laboratories

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Reference Lamps



- blackbodies not being practical, NIST started to use specially designed lamps of known spectral power distribution as standards
- repeatability of lamp manufacturing is good enough to duplicate these standard lamps
- burning time of these devices is limited



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Reference Lamps



- NIST FEL standard lamp is the mother standard for derivatives, but expensive and hard to obtain
- a family of tungsten halogen lamps of 1000, 200 and 45 W was developed for general use
- problem common to all lamps: small filament area makes uniform large-area irradiation difficult – and diffuse filters would alter lamp spectral power distribution
- calibration of mount geometry necessary

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Viewing Booths



- viewing booths offer precisely controlled viewing environments for color comparisons and product evaluations
- lamps are calibrated to exact standards, and have to be regularly exchanged
- illuminants chosen from standardized lights (D65, A, F2 (CWF) etc.)
[cool white fluorescent light]



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Viewing Booth Application



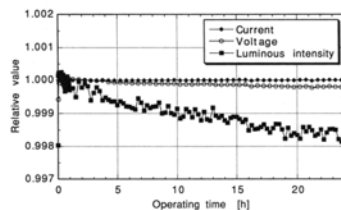
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Lamp Aging



- new incandescent lamps lose 10% brightness during the first few percent of lamp life → *seasoning* of standard lamps
- even after seasoning, all incandescent bulbs suffer some degradation over time due to filament thinning, bulb blackening, etc.
- storage stability!



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Reflectance Standards



- 2 types of standard are used:
 - ◆ **transfer standards** (materials of precisely known reflectivity) are used to bring the calibration of different instruments into line
 - ◆ **working standards** are used to calibrate one particular instrument; individual samples are usually permanently associated with the instrument they calibrate.

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Whiteness and White Standards



- **white** = high luminance & zero purity
- personal bias of most observers
- depends on
 - ◆ illumination conditions
 - ◆ environment
- ideal theoretical definition:
 - ◆ diffuses light perfectly
 - ◆ spectral reflectance = 1 for all visible λ
 - ◆ does not exist in practice!

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Reflectance Standards



- all reflectance standards used for instrument calibration should be or have:
 - ◆ mechanically robust
 - ◆ stable against ambient conditions
 - ◆ opaque, uniform surface
 - ◆ easy to clean
 - ◆ near uniform spectral response across visible spectrum and UV
 - ◆ no fluorescence effects

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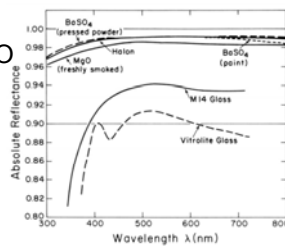
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Whiteness and White Standards



- standard whites:
 - ◆ magnesium oxide MgO
 - ◆ barium sulfate BaSO₄
 - ◆ polytetrafluorethylene (PTFE)
 - ◆ ceramic tiles
 - ◆ ...



- CIE **whiteness**:

$$W = Y + 800 \cdot (0.3138 - x) + 1700 \cdot (0.3310 - y)$$

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Color Reflectance Standards



- normally not used to calibrate instruments, but to have objects of predefined spectral power distribution that one can include in scenes
- old standard: NPL ceramic tiles [National Physical Lab]
- new standard: **GretagMacbeth ColorChecker** (many others exist)
 - ◆ 24 patches
 - ◆ 18 colors (1 fluorescent)
 - ◆ 6 greys

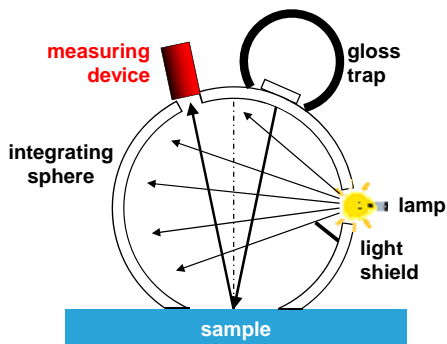


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Color Measuring Configuration



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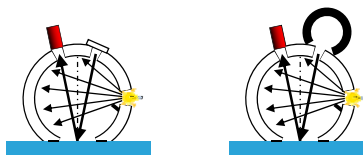


Color Measuring



- integrating sphere: white-diffusing material
- $P_1(\lambda)$... measurement with closed hole
- $P_2(\lambda)$... measurement with open hole
- gloss estimation:

$$\text{gloss}(\lambda) = \frac{P_1(\lambda) - P_2(\lambda)}{P_1(\lambda)}$$



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Spectroradiometer Design



- key components needed:
 - ◆ reliable broadband sensor for light with known spectral response curve
 - ◆ reliably controllable source of monochromatic light to scan the entire visible spectrum
- provisions for repeatable and controlled specimen mounting and illumination have to be made

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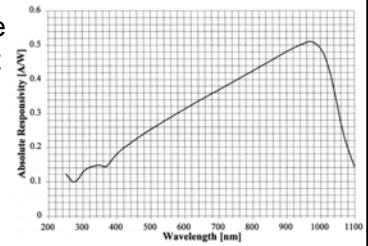
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Silicone Photodiodes



- the light-sensitive elements in most radiometric and photometric instruments are silicon photodiodes
- these devices yield a wavelength-dependent current per radiant energy that hits them
- used as absolute detector for monochrome light



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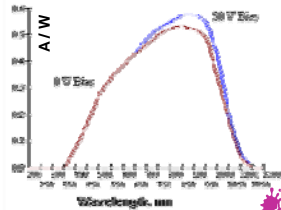


Silicone Photodiodes



- **Photodiode Responsivity**
- the measure of sensitivity is the ratio of radiant energy incident on the photodiode (in watts/cm²) to the photocurrent output (in amperes/cm²).

It is expressed as the **absolute responsivity** (in amps per watt).



source: home.sandiego.edu/~ekin/photodiode/ptdtech.html

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Monochromators



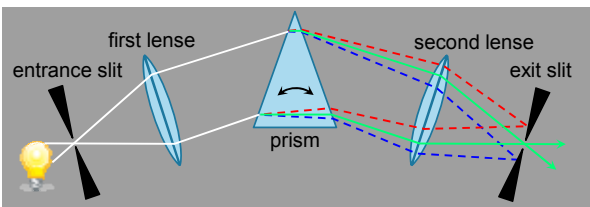
- main sources of monochrome light:
 - ◆ **filters** – inflexible (one per sample, no intermediaries), plus usually too wideband
 - ◆ **lasers** – inflexible (same as above), expensive
 - ◆ **prisms** – nonlinear wavelength dependency, but pure output
 - ◆ **gratings** [Beugungsgitter] – linear dependency on wavelength, but higher-order diffraction effects affect purity of result

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Prism Monochromator



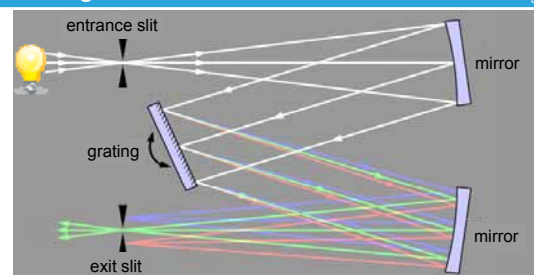
each wavelength is focussed to a different position at the exit slit: the transmitted wavelength through the slit depends on the rotation angle of the prism

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Grating Monochromator



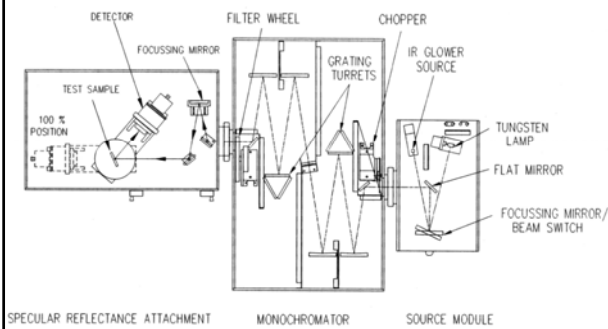
each wavelength is focussed to a different position at the exit slit: the transmitted wavelength through the slit depends on the rotation angle of the grating

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Spectrophotometer Components



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Professional Spectrophotometer (1)



- internal arrangements basically as shown in previous sketch
- 10 nm resolution from 380 to 780 nm, 18 kg
- 2 gratings, 15 cm sphere
- extremely high inter-device agreement
- capable of eliminating fluorescence effects

Minolta CM-3720d



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Professional Spectrophotometer (2)



- internal arrangements differs from sketch - direct light path to grating
- 0.9 nm resolution from 380 to 780 nm, 6 kg
- 0.1° – 1° measurement angle
- 0.003 – 500,000 cd/m²
- various lenses (wide angle, tele etc.) available

Minolta CS-2000



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Gretag Macbeth Spectrolino



- handheld device
- 10 nm resolution, 380 to 780 nm
- has to be attached to a computer via serial port
- only really useful with the accompanying software
- modern version: Eye-One (USB)



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Spectroscan



- used for fast, routine scanning of opaque and transparent color charts
- color charts are produced to calibrate printing equipment
- a Spectrolino is used as the measurement tool

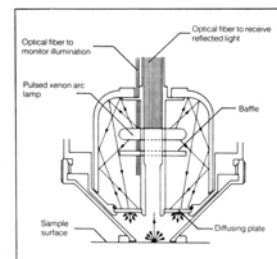


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Chroma Meters (1)



- principle: a diffusor spreads light over 3 photocells which are covered by CIE XYZ-related filters
- available in
 - ◆ self-illuminating and
 - ◆ passive versions
- only records chroma and luminance values which are specific to a given illuminant

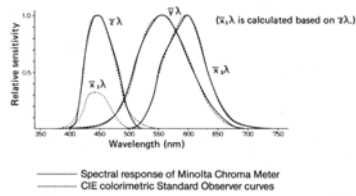


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Chroma Meters (2)



- cannot be used to predict appearance
- still very useful for industrial quality control
- good at finding *color differences* in production lines
- much simpler & cheaper than spectrophotometers



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Minolta ChromaMeter CR-400



- typical device for industrial use
- principle unchanged over past decades, new devices are just more user-friendly
- separate data processor and measurement head
- head can be used separately and/or connected to a computer



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