# Unwildering the Bewildering Panoply of Color Measurement Devices

John Seymour

John the Math Guy, LLC

# Part 1

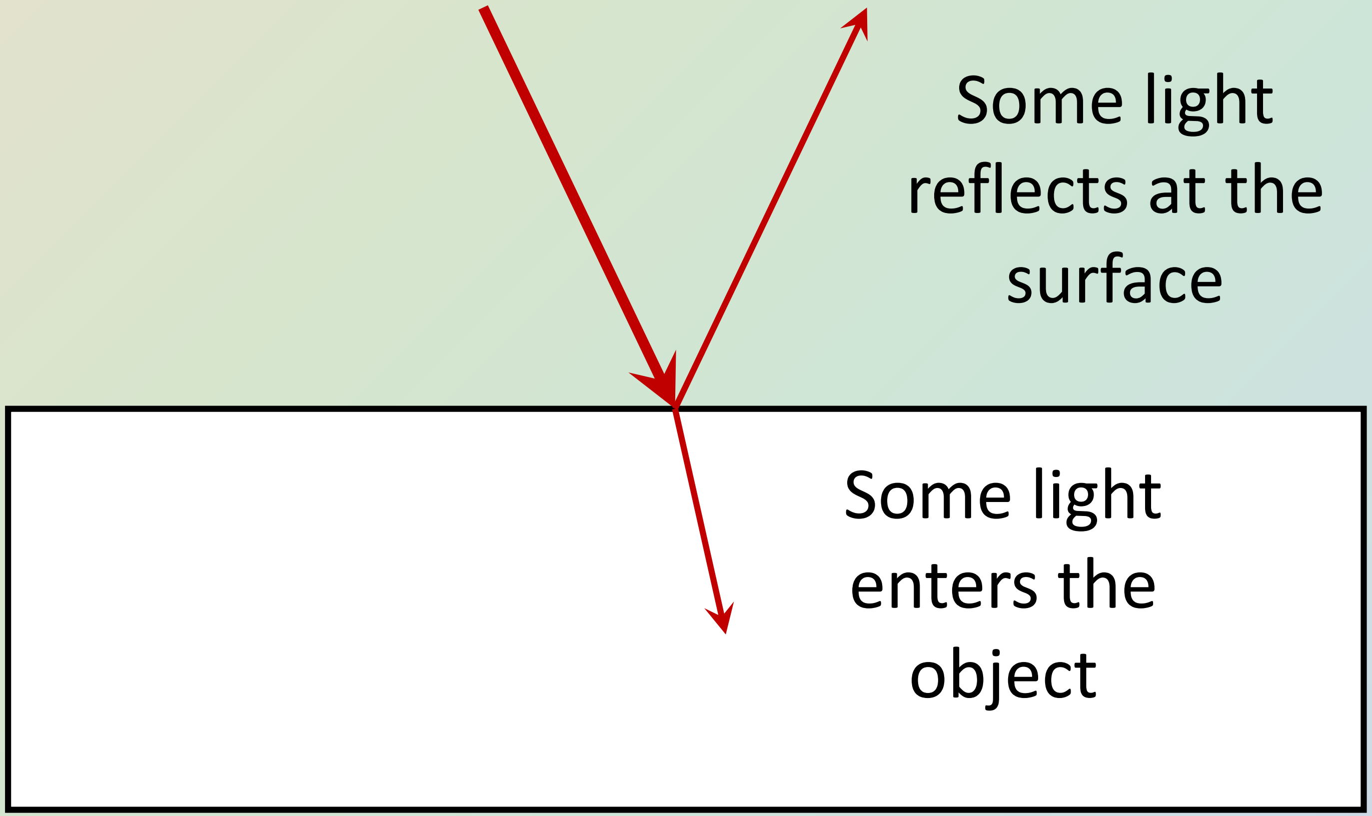
*Light reflects from stuff and then we see it*

# The laws of reflection

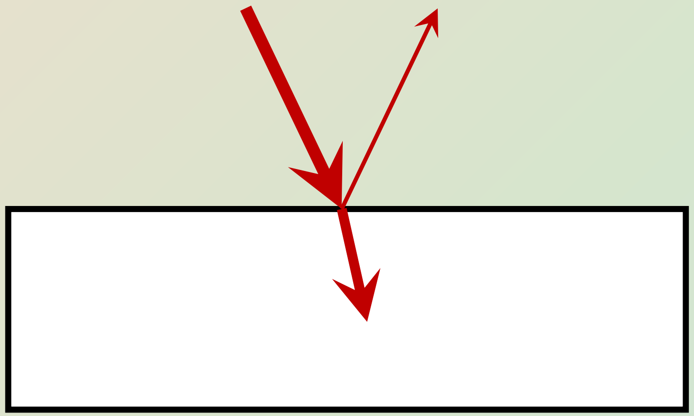
- Fresnel's law
  - Depends on angle
  - Depends on difference of indices
- Snell's law
  - Discovered by Ptolemy
  - Important for lenses and bent pencils
  - Perhaps not worth mentioning in this discussion
- Billiard's law
  - Effect of a rough surface

http://johnthemathguy.blogspot.com/2014/08/when-light-reflects-from-stuff.html

# Fresnel's law

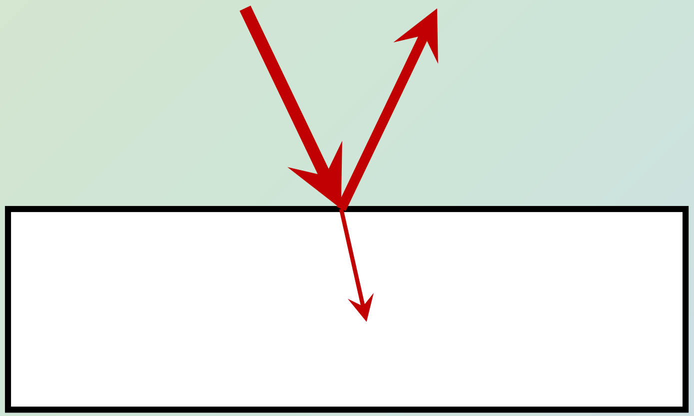


# Fresnel's law



Little
reflection at
optically soft
surface

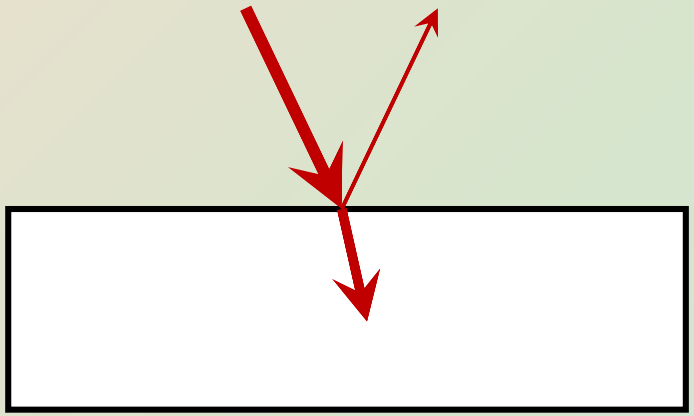
Water, soft plastics,
anti-reflective coatings ($MgF_2$)



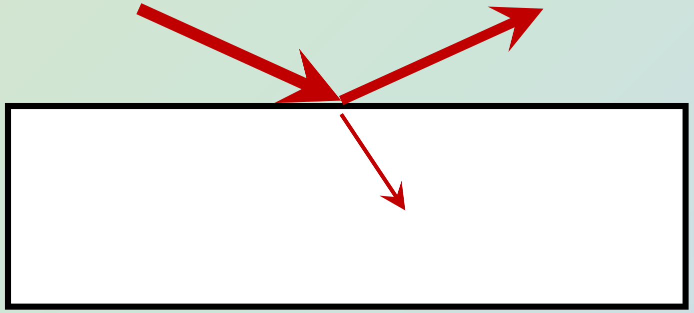
Much
reflection at
optically hard
surface

Glass, diamond, mirrors

# Fresnel’s law



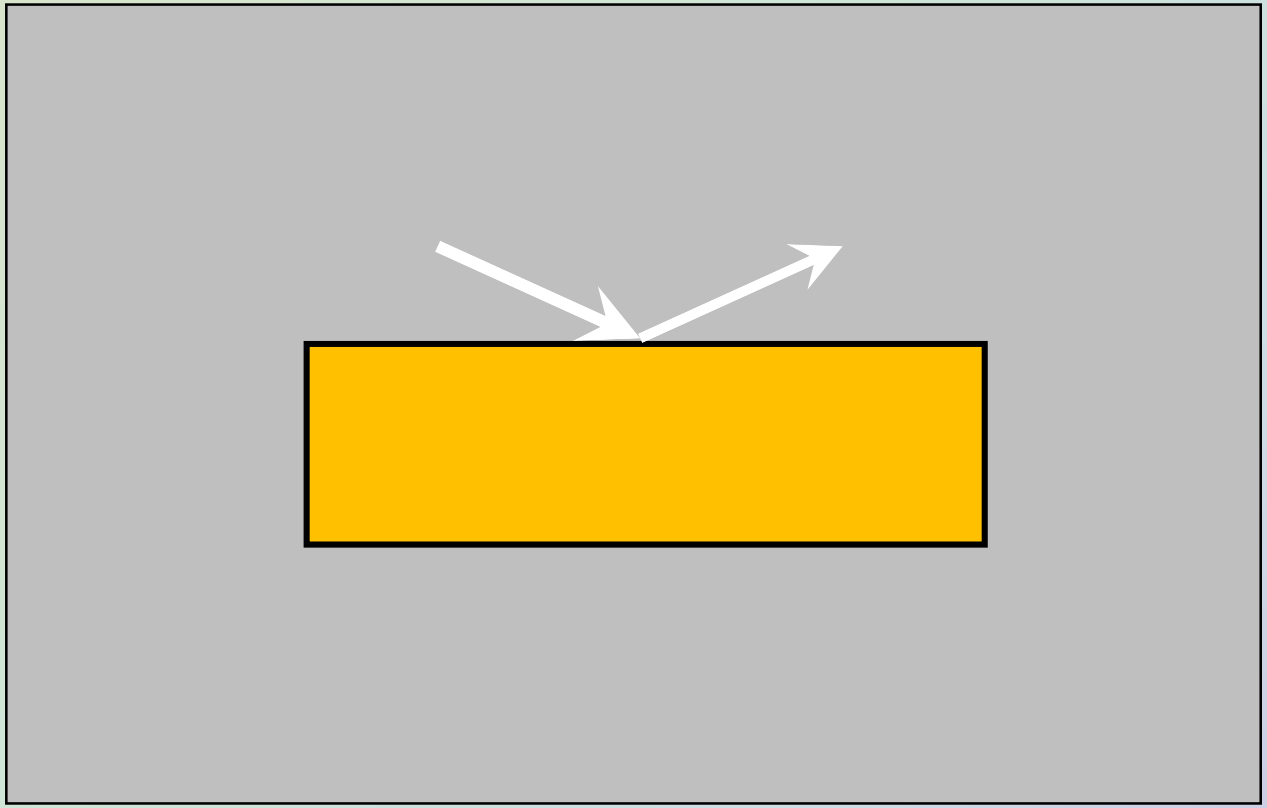
Little
reflection at
high angle



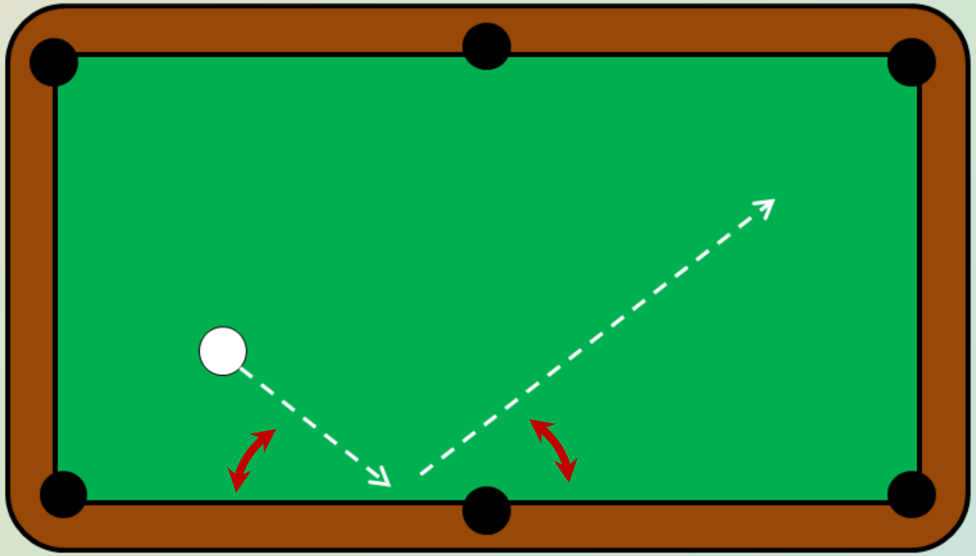
Much
reflection at
shallow angle

# Fresnel’s law

Surface reflection doe not interact with the object, so white light is reflected.



# Billiard's law

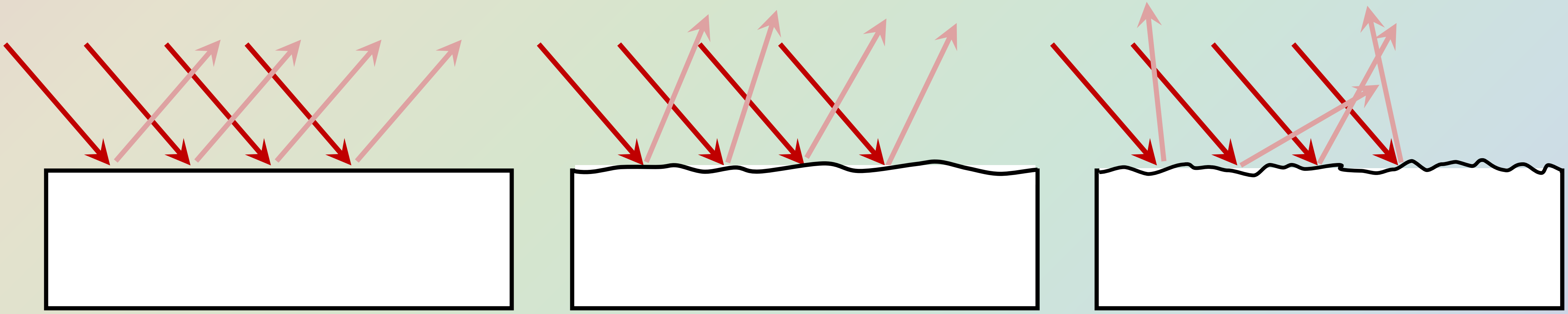


Angle of incidence

=

opposite of angle of reflectance

# Billiard’s law



Smooth surface, glossy

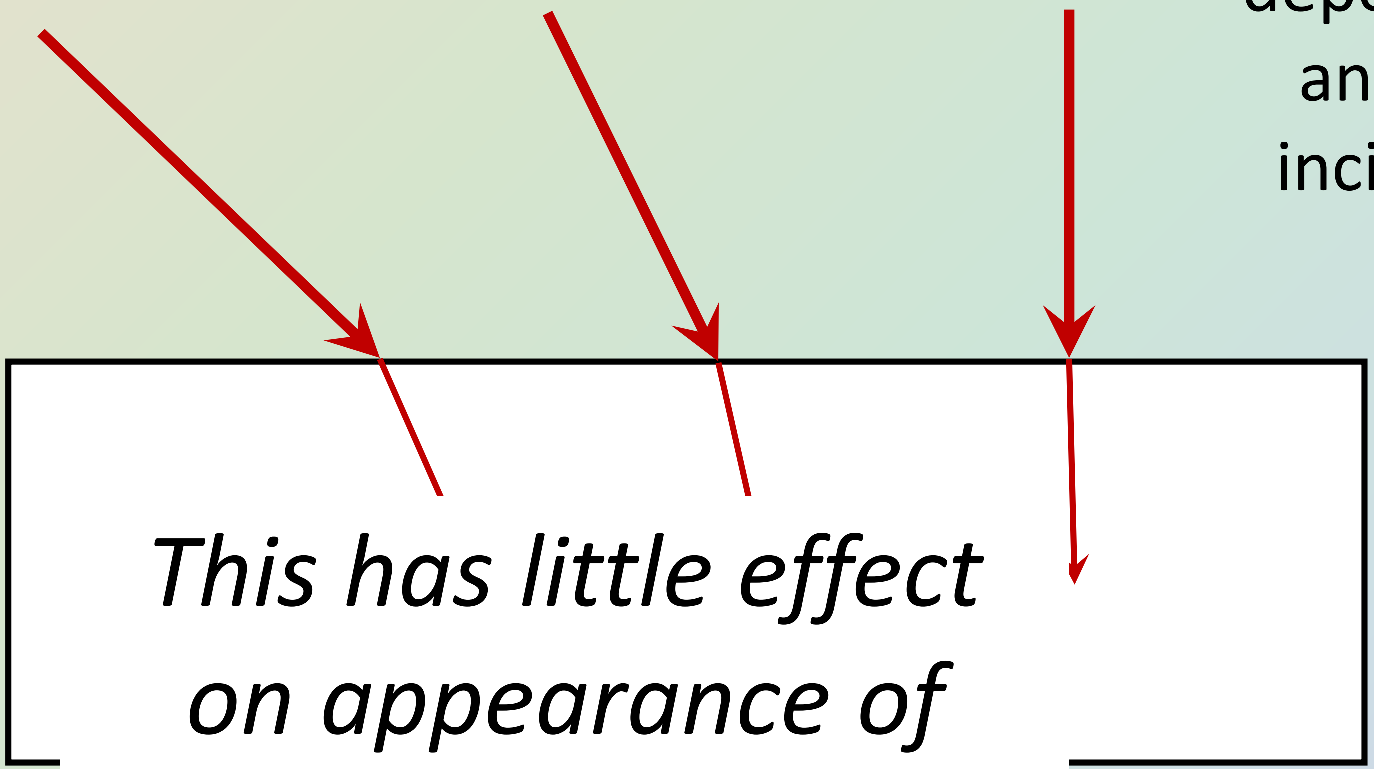
Kinda smooth, semi-glossy

Rough surface, “flat” or matte

http://johnthemathguy.blogspot.com/2012/07/flat-paint-is-not-flat.html

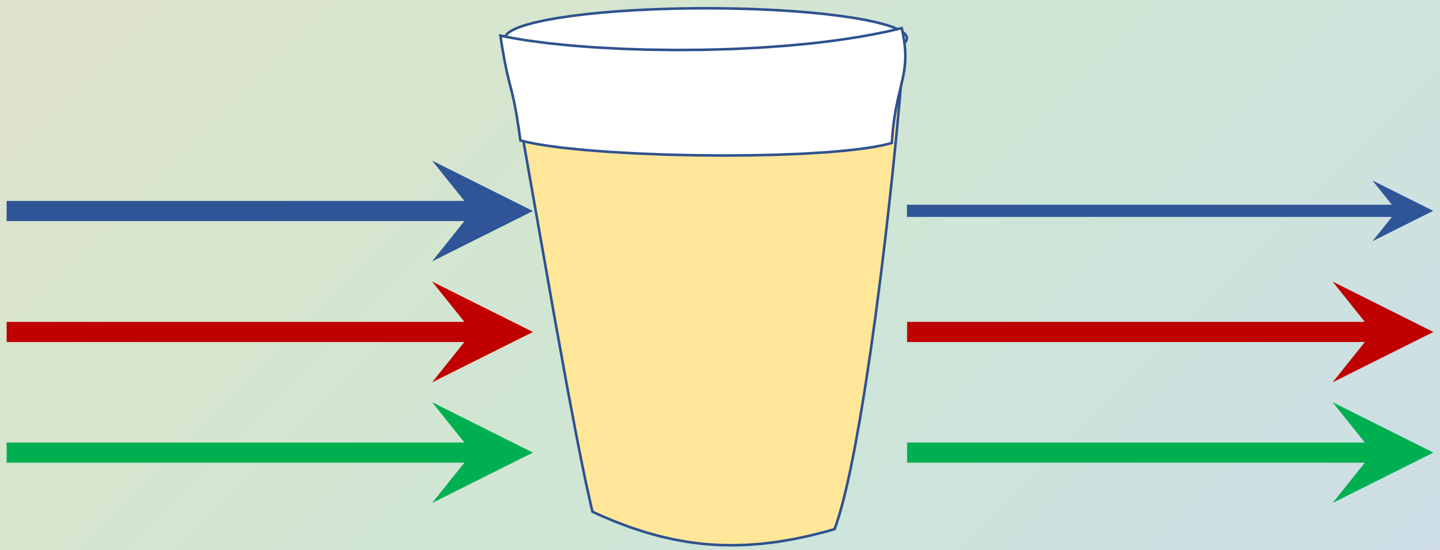
# Snell's law

The bend depends on angle of incidence



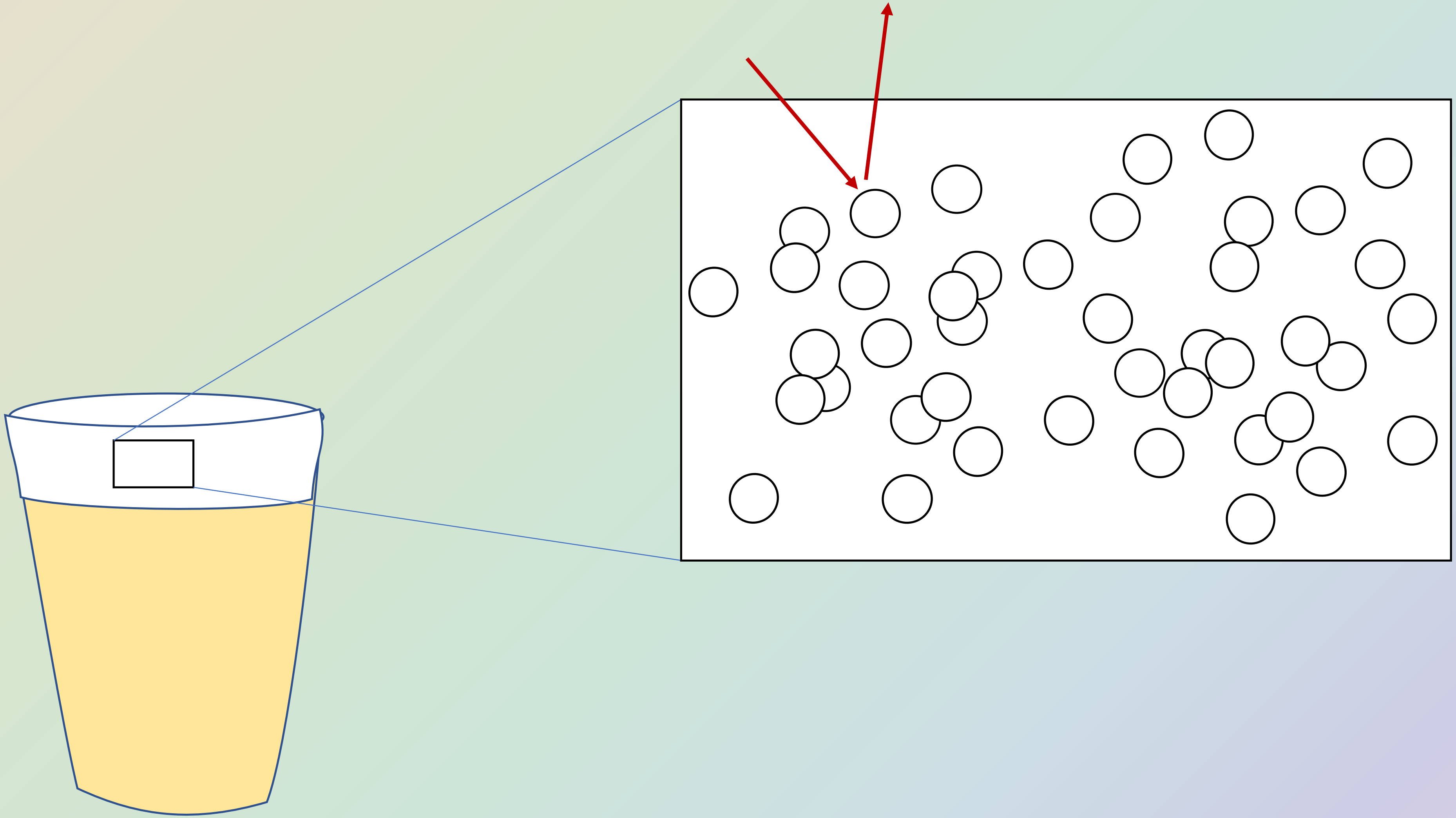
*This has little effect on appearance of objects!*

# Absorption (Beer's law)



# Scatter

# Scatter



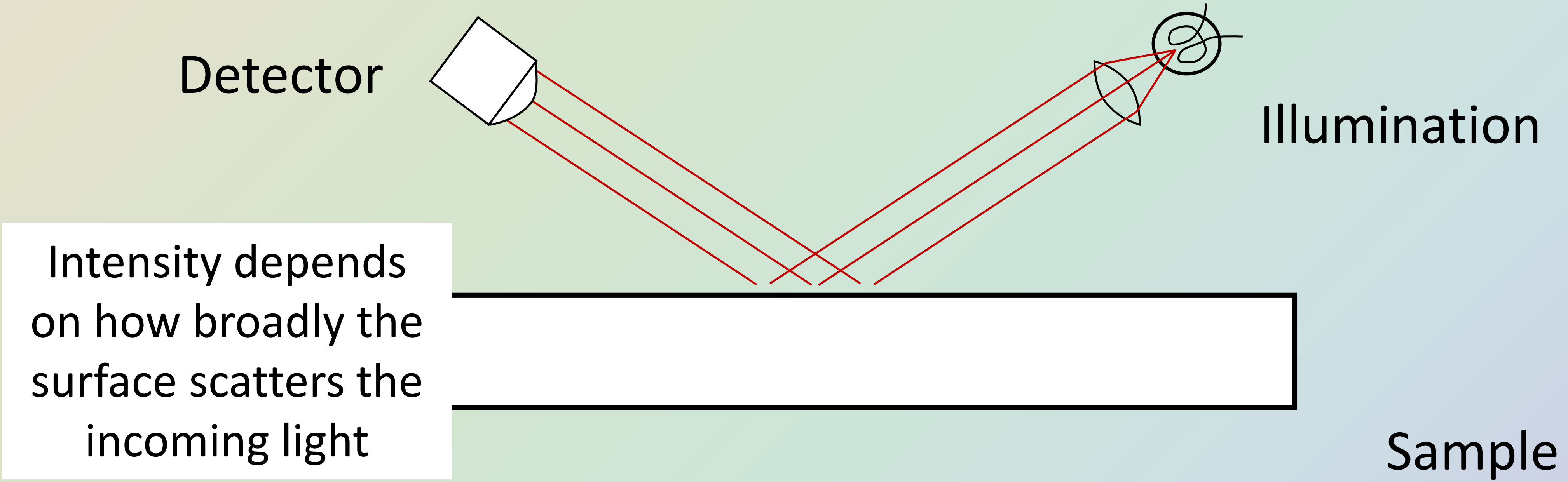
# Absorption and Scatter

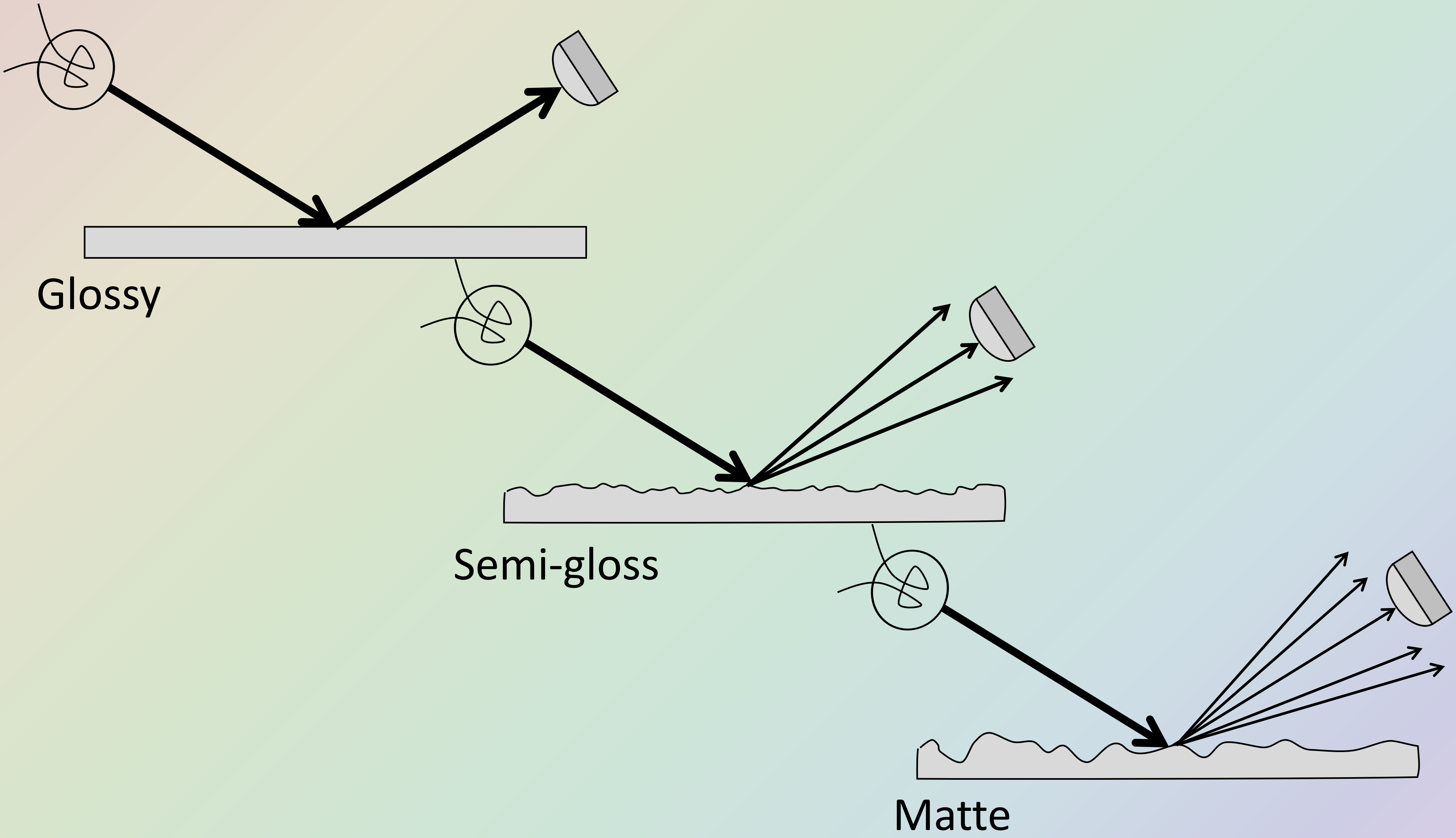
- Kubelka-Munk equation

# Part 2

*This is not to be glossed over*

# Generic glossmeter





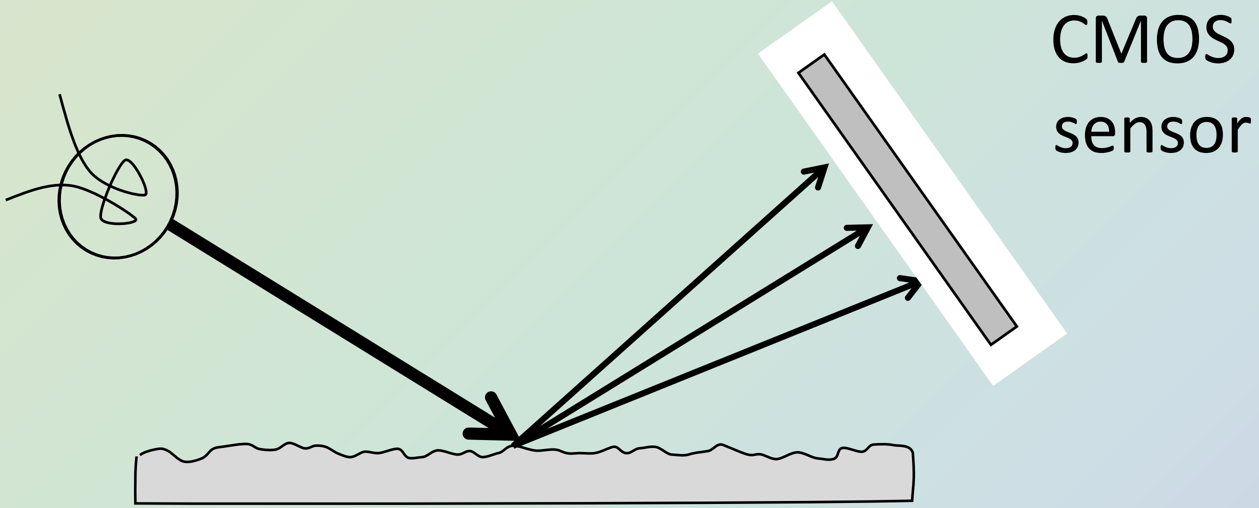
Glossy
Semi-gloss
Matte

# Glossmeter angles

- Fresnel – amount of reflection depends on
  - Optical hardness
  - Angle of incidence
- Illumination and detection angles always opposite
- Recommendations for angles
  - High gloss – $20^o$
  - Medium gloss – $60^o$
  - Low gloss – $85^o$

# Metallic luster

- The degree that you can see objects reflected
- Tough to measure



# Part 3

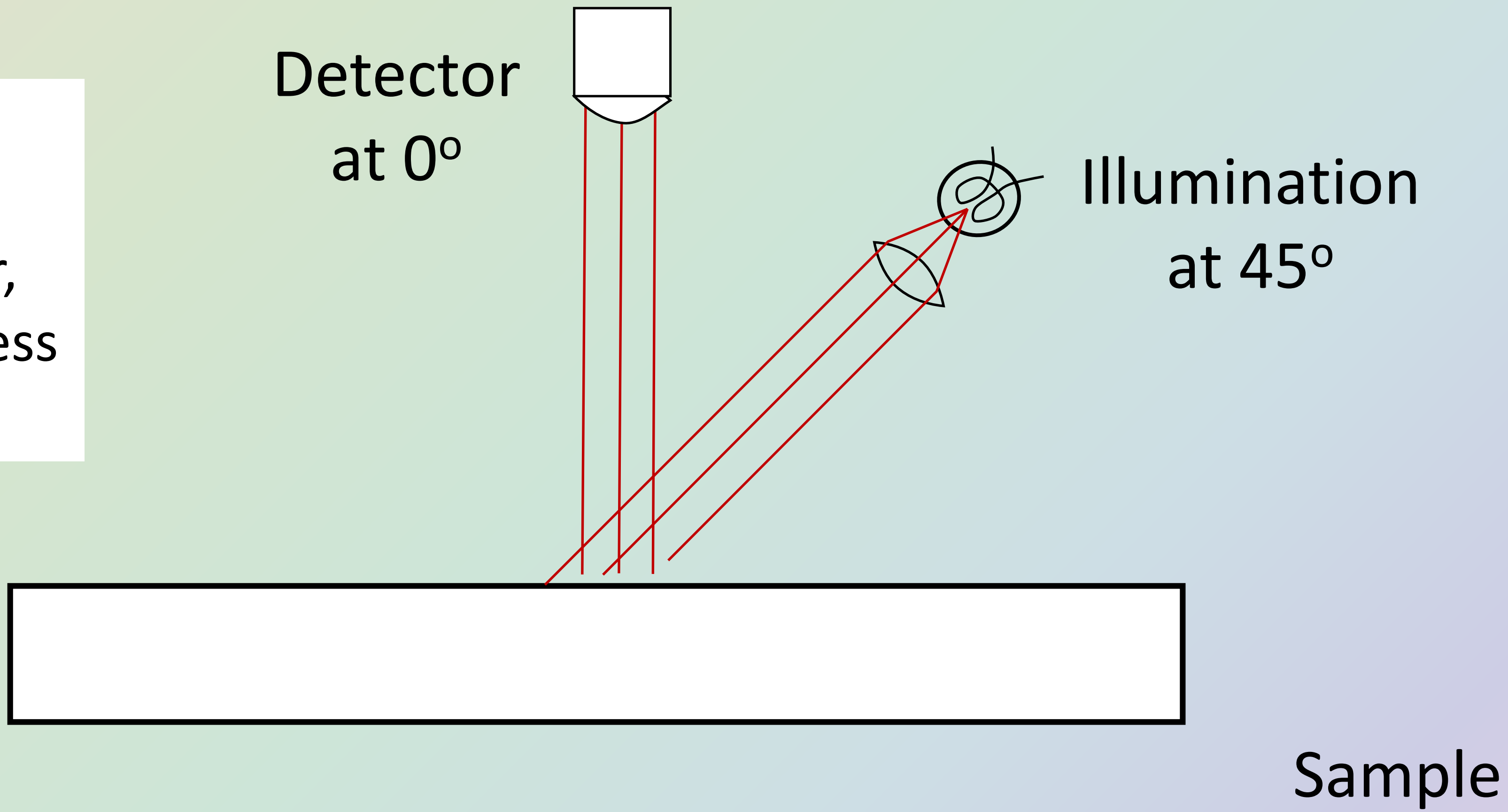
*Getting to*
*the bulk of it*

# Two popular geometries

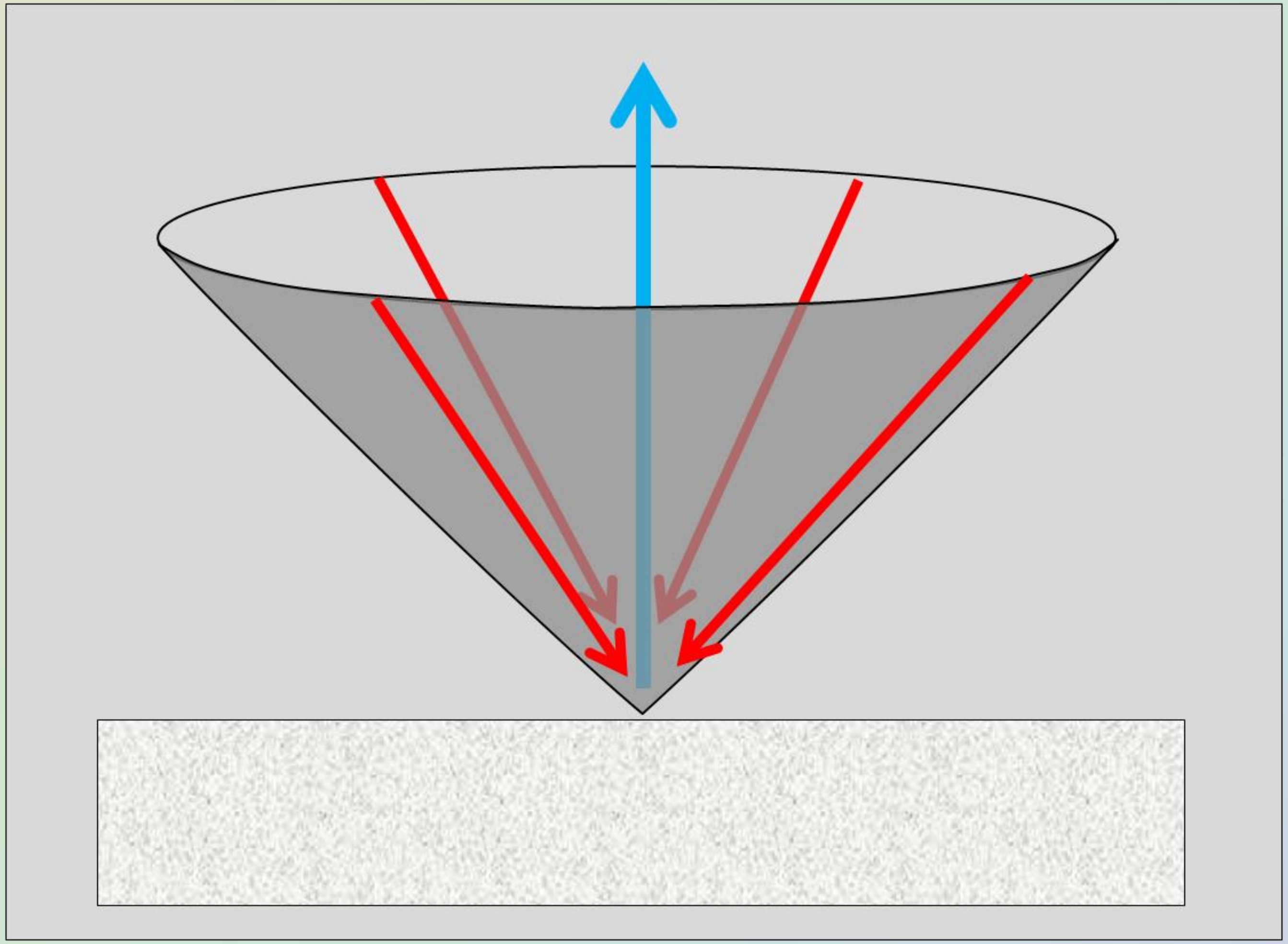
- 45/0
- Spherical, 8/d

# 45/0

Detector sees:
bulk reflection and
some of the specular,
depending on roughness
of the surface

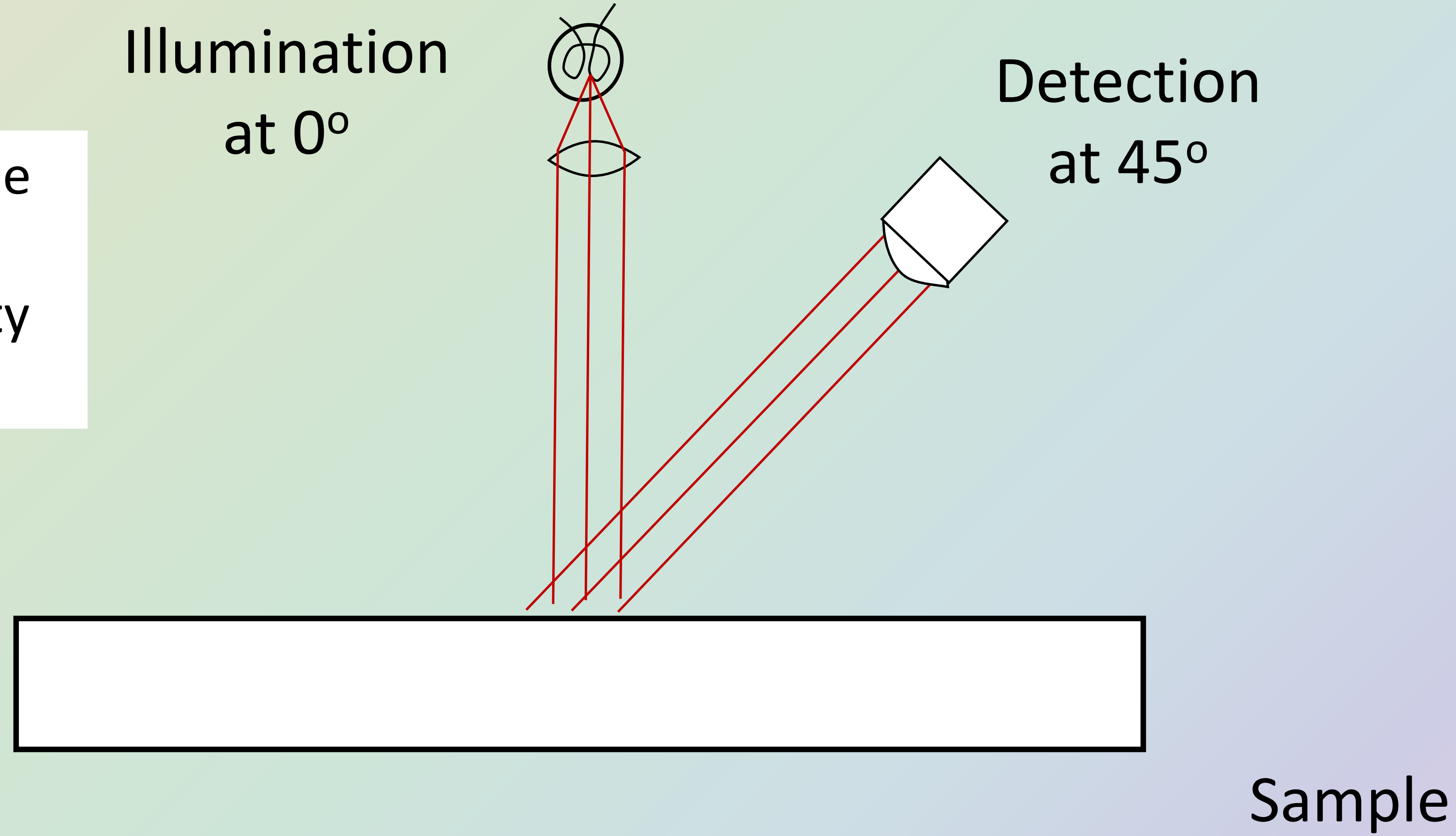


# 45/0 with annular ring illumination



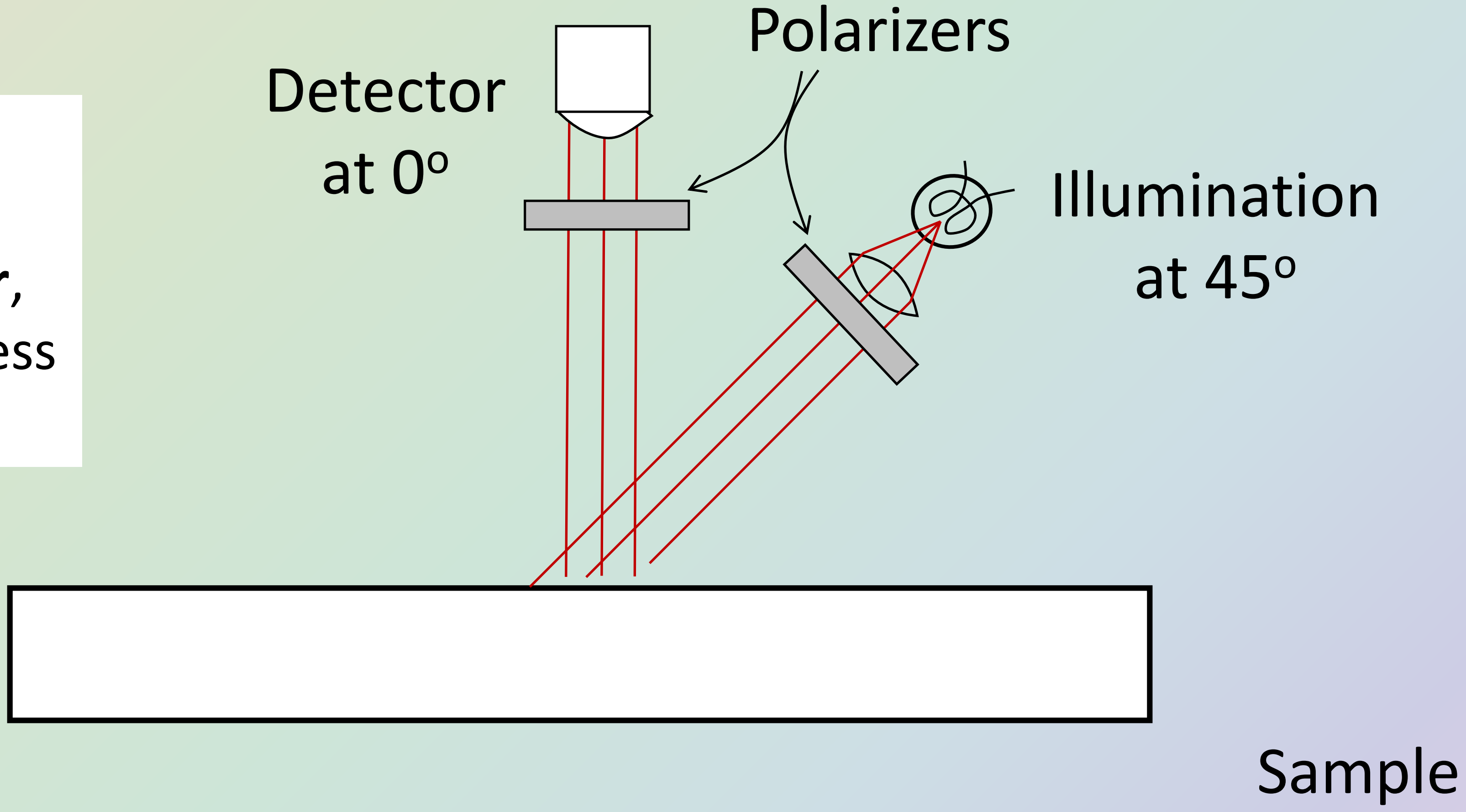
# 0/45

Surprisingly, reads the same as 45/0: Helmholtz Reciprocity Principle



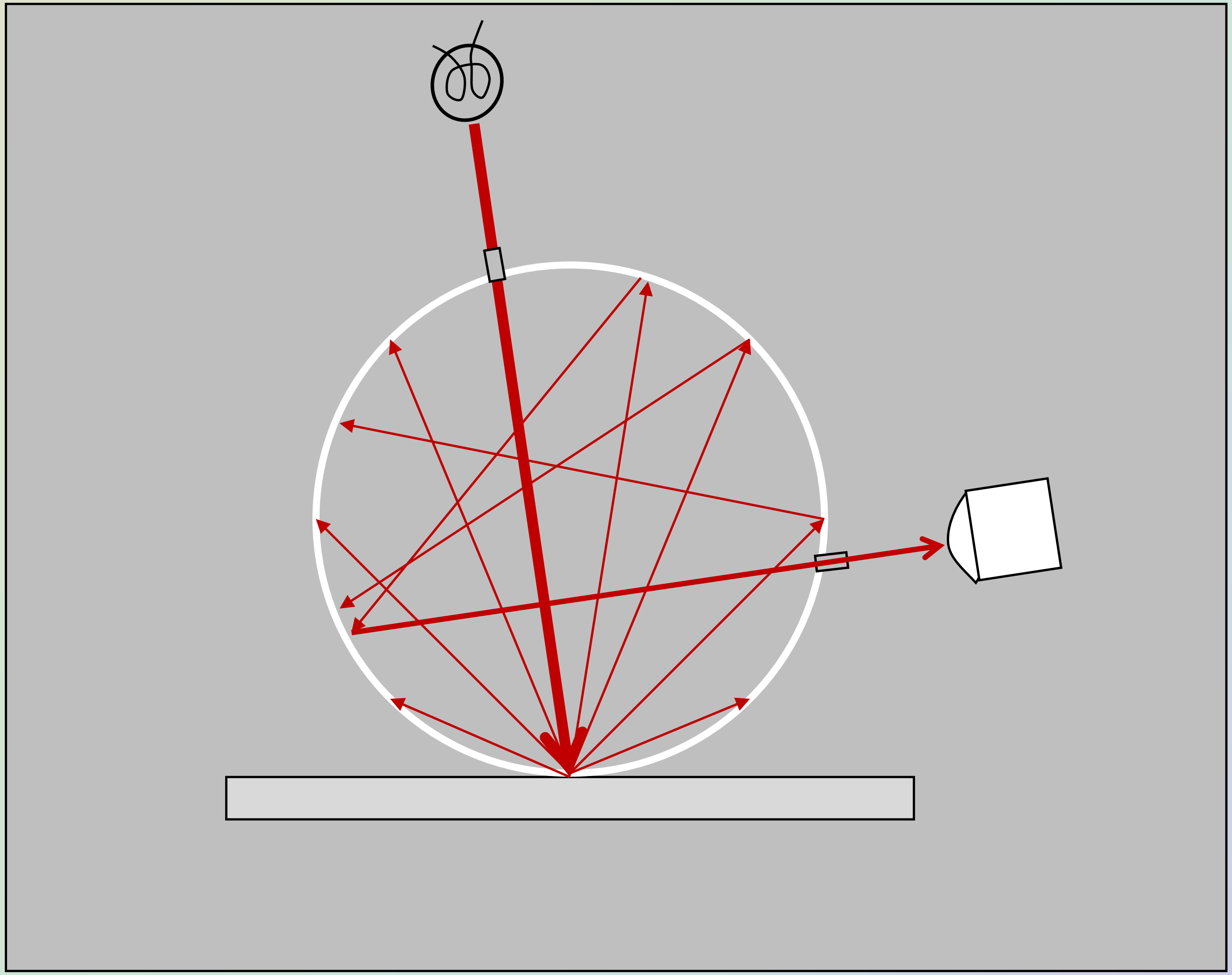
# 45/0, cross polarized

Detector sees:
bulk reflection and
NONE **of the specular**,
depending on roughness
of the surface

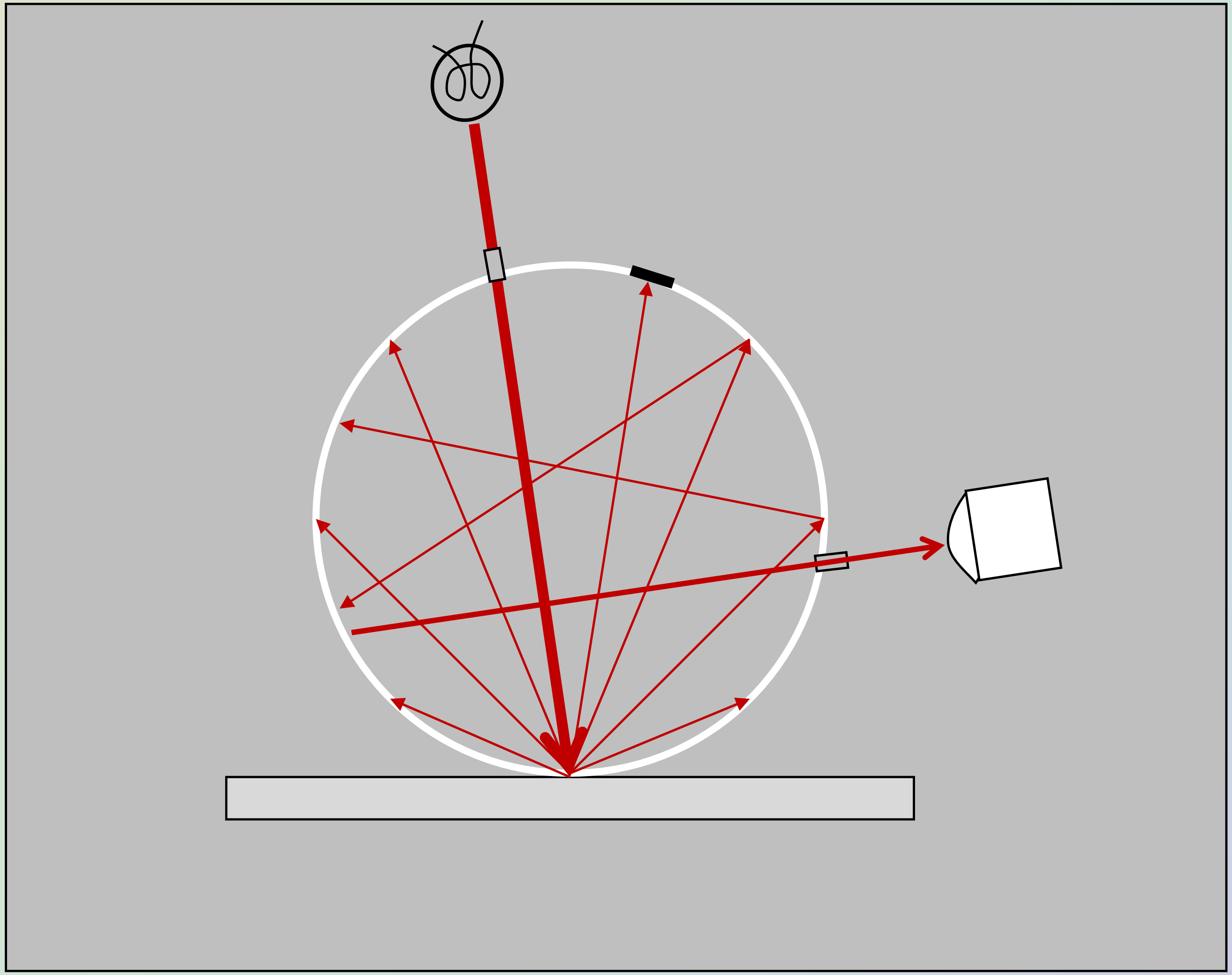


# Correlates well with…

# Spherical (8/d, Specular Included)



# Spherical (8/d, Specular Excluded)



# Spherical

- Uses integrating sphere
- Collects all the light, or all of the light except for direct specular

http://johnthemathguy.blogspot.com/2014/10/a-guide-to-reflectance-measurement.html

# Two popular geometries

- 45/0
- Spherical, 8/d
- Goniospectrophotometer

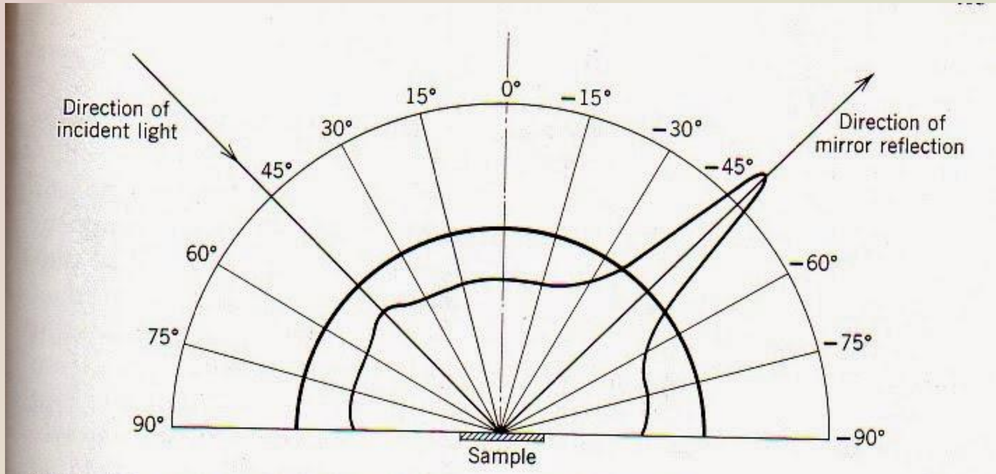
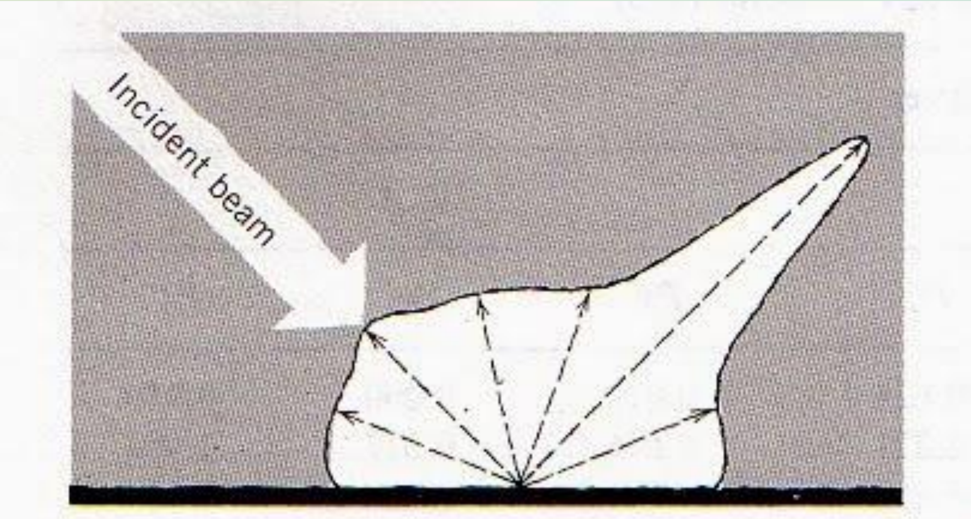



**Figure 3.6** Goniophotometric record of the perfect reflecting diffuser (perfect semicircle) and a semiglossy sample (near semicircle bulged out in direction of mirror reflection). Direction of incident light is set at 45 degrees and directions of view range from +90 to −90 degrees. The direction of incident light, the direction of view, and the normal to the sample are in the same plane.

*Color in Business, Science, and Industry, Judd and Wyszecki, 1975*




**Indicatrix of a typical "glossy" sample.**

*Principles of Color Technology, Billmeyer and Saltzman, 1981*

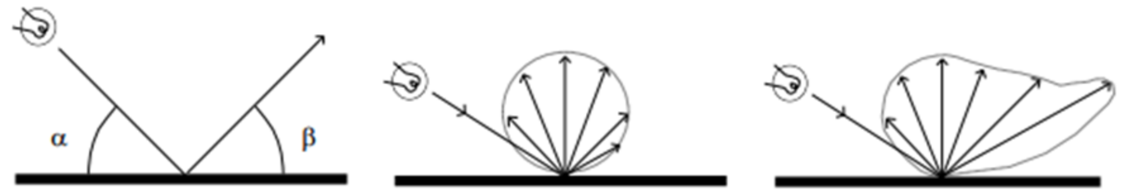



*Figure 6 - specular reflection (when $\alpha = \beta$)*

*Figure 7 - matte reflection*

*Figure 8 - general reflection*

*Goniophotometry of Printing Ink, Seymour, TAGA 1996*

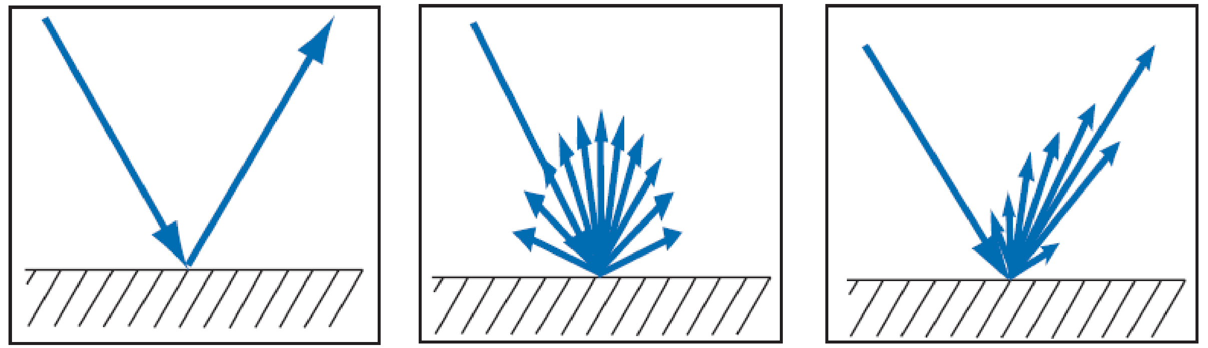


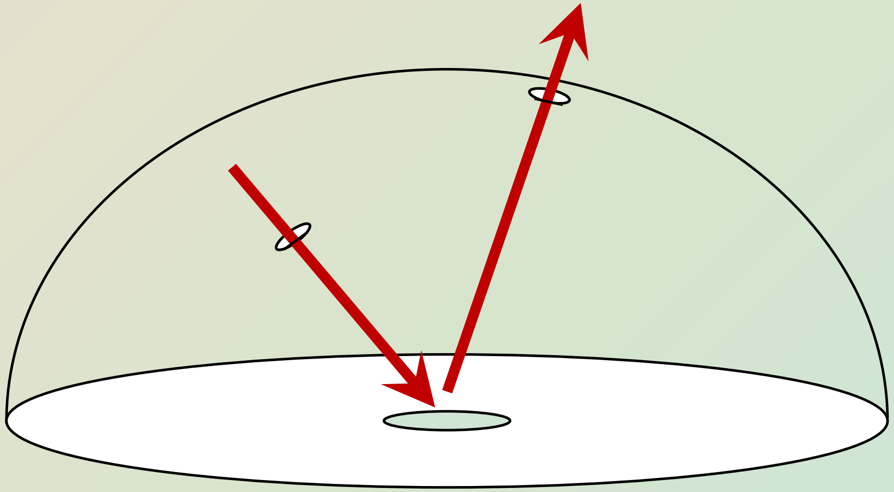
**Fig. 3**
Perfectly specular surface: 100% reflection

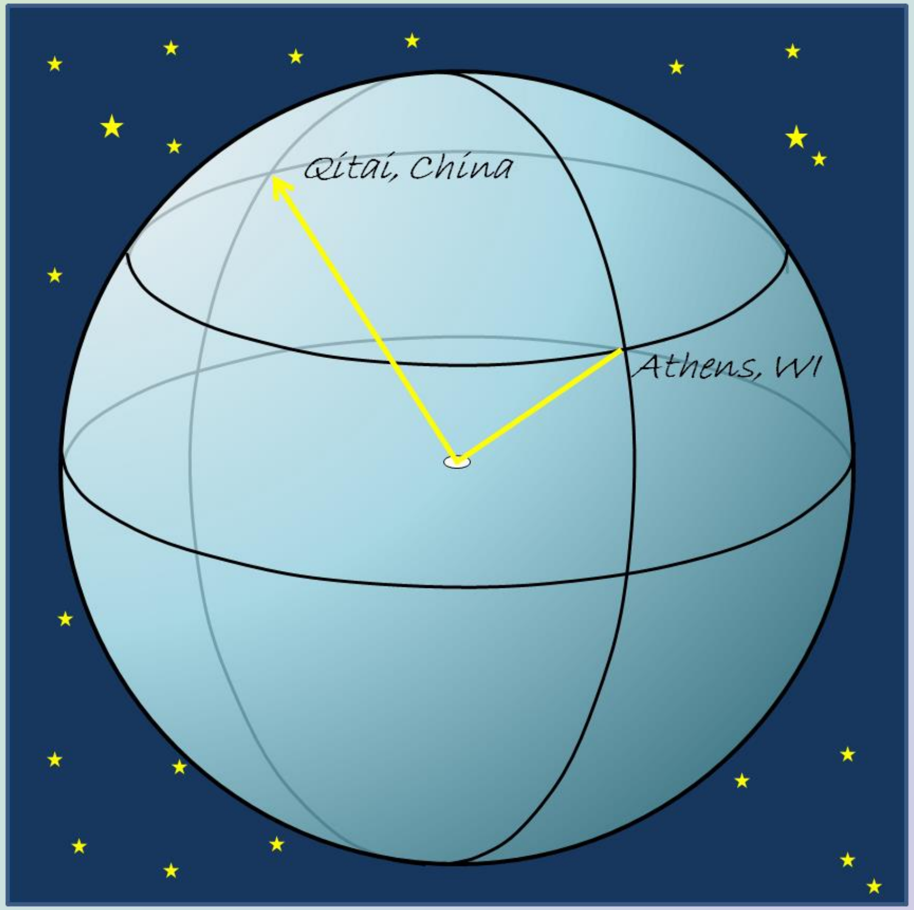
**Fig. 4**
Perfectly dull surface: 100% scattering

**Fig. 5**
Metal effect: reflection and scattering

*Improving Metallic Ink Printing through Polarized Densitometry, Mannig and Verdeber, 2002*

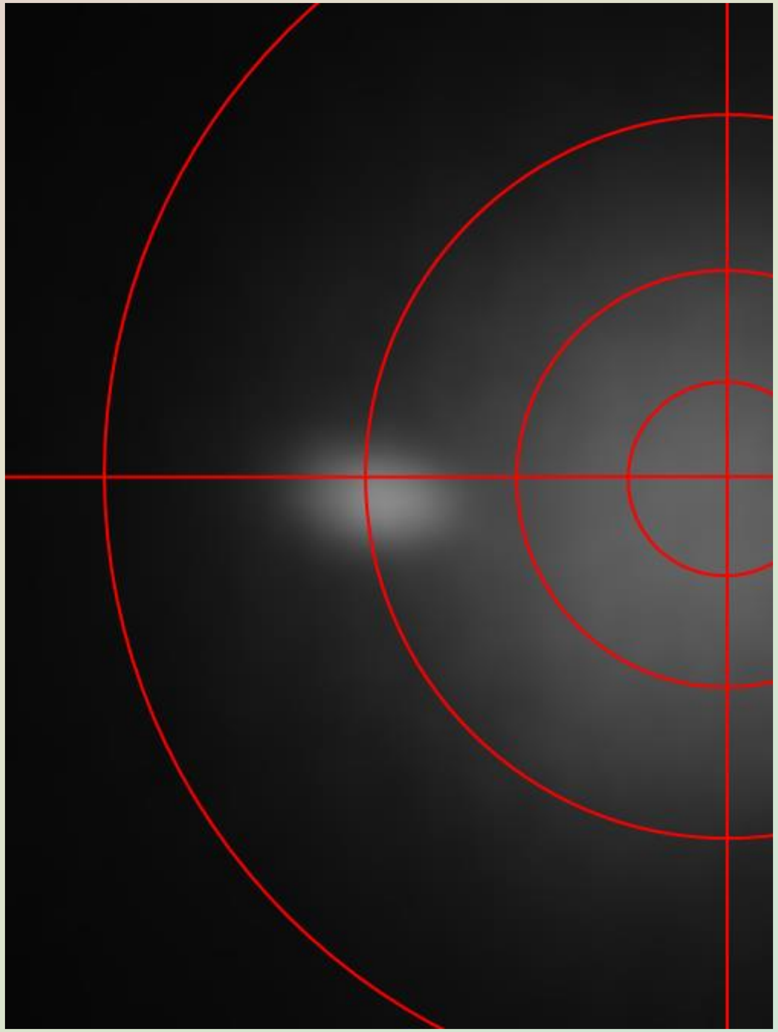
# Goniospectrophotometer, conceptual



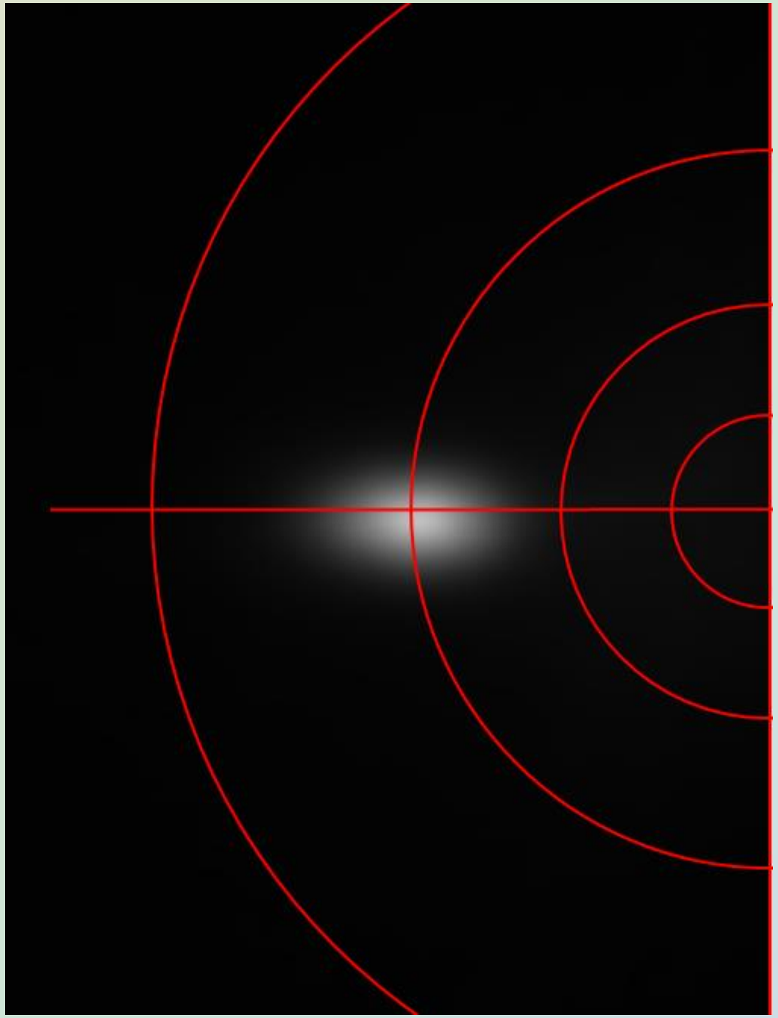



http://johnthemathguy.blogspot.com/2014/08/an-illustrated-compendium-of-indicatrix.html

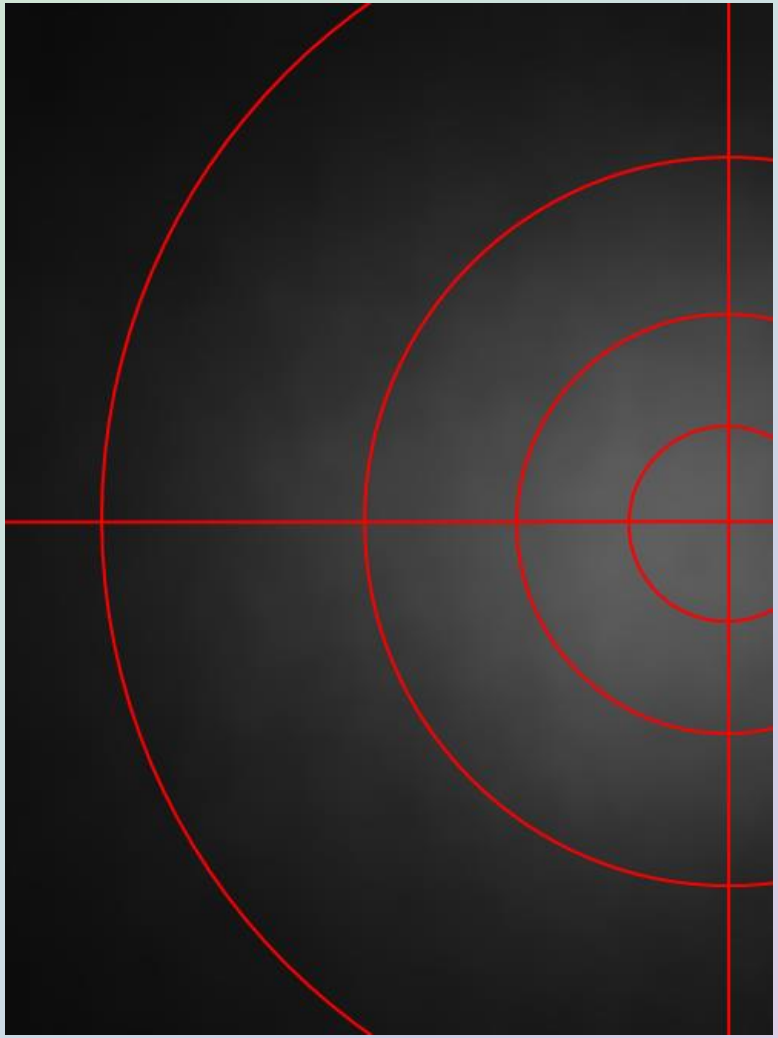
# Some indicatrices



*White semi-glossy paper*



*Black ink on glossy paper*



*Dull aluminum foil*

# Recap

- Bulk and specular
  - Spherical geometry, with specular
- Bulk without smooth-surface specular
  - Spherical geometry, “without” specular
- Only bulk
  - 0/45 or 45/0
- Really only the bulk
  - 0/45 with cross polarizers
- Everything, separated out

# Part 4

*What property do I want to measure?*

*And why???*

# I want the expensive, glossy look

## Why does my cyan have the blues?

### From John Seymour – The Maths Guy

When I started in the print industry as an apprentice way back when, I noticed that the folks in the press room called the inks red, yellow and blue. This confused me. Everything I had read in colour theory books said that cyan, magenta and yellow were the subtractive primaries. The primaries you use to make a wide range of colours with pigments and filters. Pigments and filters work by subtracting certain wavelengths of light. On the other hand, red, green and blue were the additive primaries and were used to make all the colours when you are mixing light, as in a TV or computer monitor.

Why were these printers calling some of the additive and some of the subtractive primaries? Didn't they realise that this reduced their gamut? That was the theory anyway. Support Footnote [1]

Is it just a naming issue? Because Cyan ink is blue and magenta is red.

It took me a few years to realise that pressmen were not quite as ignorant as I thought they were. I guess I spent too much time running for buckets of halftone dots as a young-un, to actually put my head in a bucket of ink. When I finally did put my head in a bucket of ink (as part of a hazing experiment – see support Footnotes [3]), I could see that cyan ink is blue and that magenta ink is red when you look at them in a bucket.

Both words came into our language

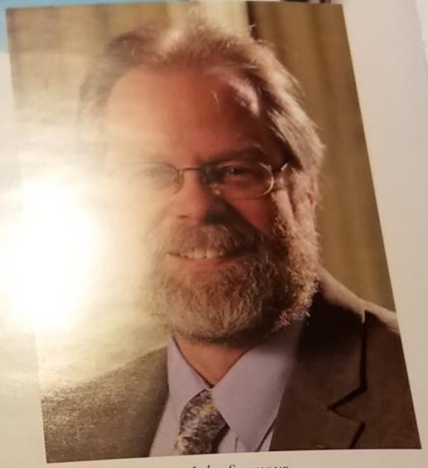
100% of red and blue light, Beer's law predicts that the double layer of magenta, will reflect 100% of the red and blue light. Beer's law would further predict that the green light would reflect at only 10% X 10%, which is 1%. A double layer of [illegible] magenta becomes a rich magenta.

A key point here: For this perfect magenta ink, the hue is still that of magenta. It still reflects most of the red and blue light and absorbs most of the green light. Let's just say that [illegible] switch over to a magenta that [illegible]. That for some inexplicable rea[illegible] printer decides on a bargain [illegible] does not reflect quite as much bl[illegible] we would hope; maybe only 40% [illegible] blue light when we put a thin film [illegible] and maybe 10% of the green light. Let's say that the red light is still reflected at 100%. What happens when we double the amount of ink on the paper? Beer's law takes over, and we see that blue light is reflected at 40% X 40% = 16%.

Green light? The reflectance goes from 10% down to 1%. Red light stays at 100%. The table below summarizes the Beer's law estimation.

| | Blue | Green | Red |
|---|---|---|---|
| Thin layer | 40% | 10% | 100% |
| Thick layer | 16% | 1% | 100% |

From this table, it would seem that the thick layer of magenta, is a lot closer to



John Seymour

Beer's law kicks in, the areas of the spectrum where the reflectance is "mid-level" (i.e. 40% reflectance), are grossly affected by the ink film thickness.

The plots below are the spectra of cyan and yellow inks. If the previous rule applies, then we would expect that cyan ink will have an appreciable change in hue as it gets thicker. From the plot of cyan ink, we see that the reflectance values between 500nm and 600nm are "intermediate", somewhere between the highest value and the darkest value. Th

# I want to measure what it looks like

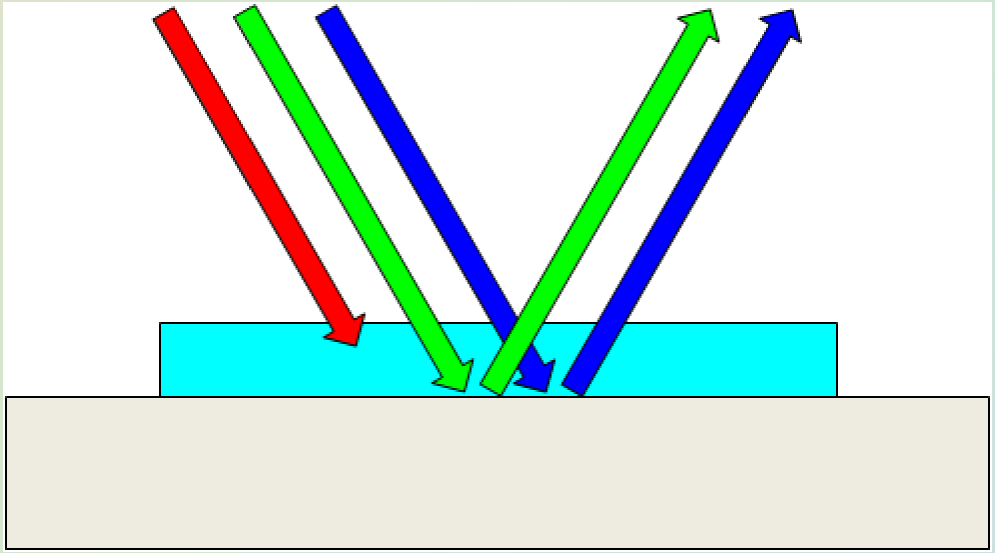
0/45

Directed sunlight

Spherical

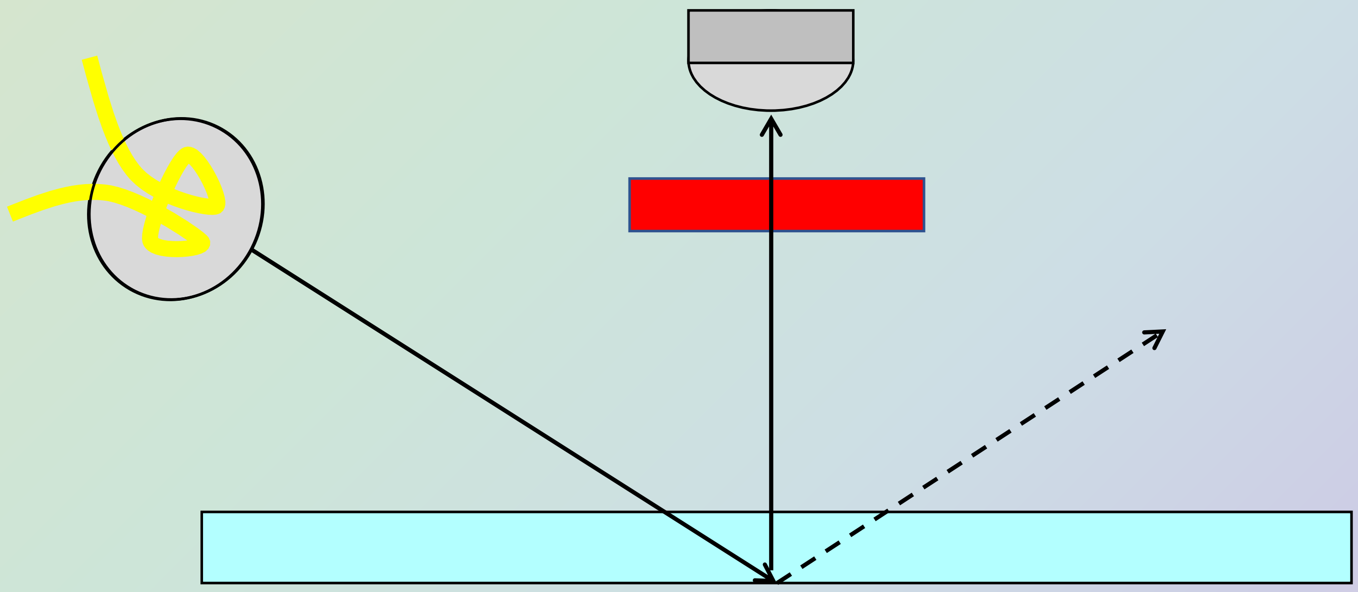
Cloudy day

# I want to measure amount of ink



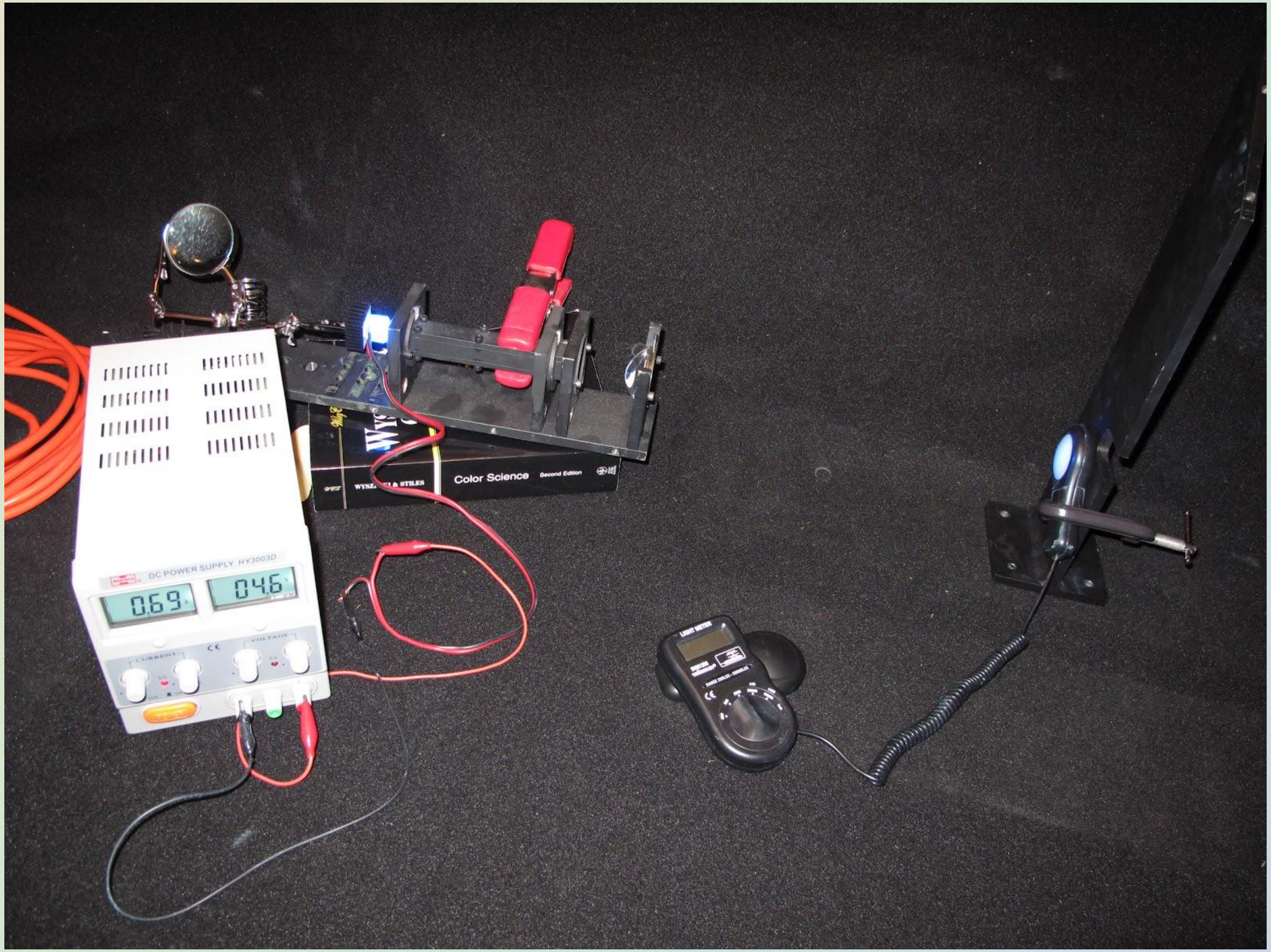
# I want to measure amount of ink

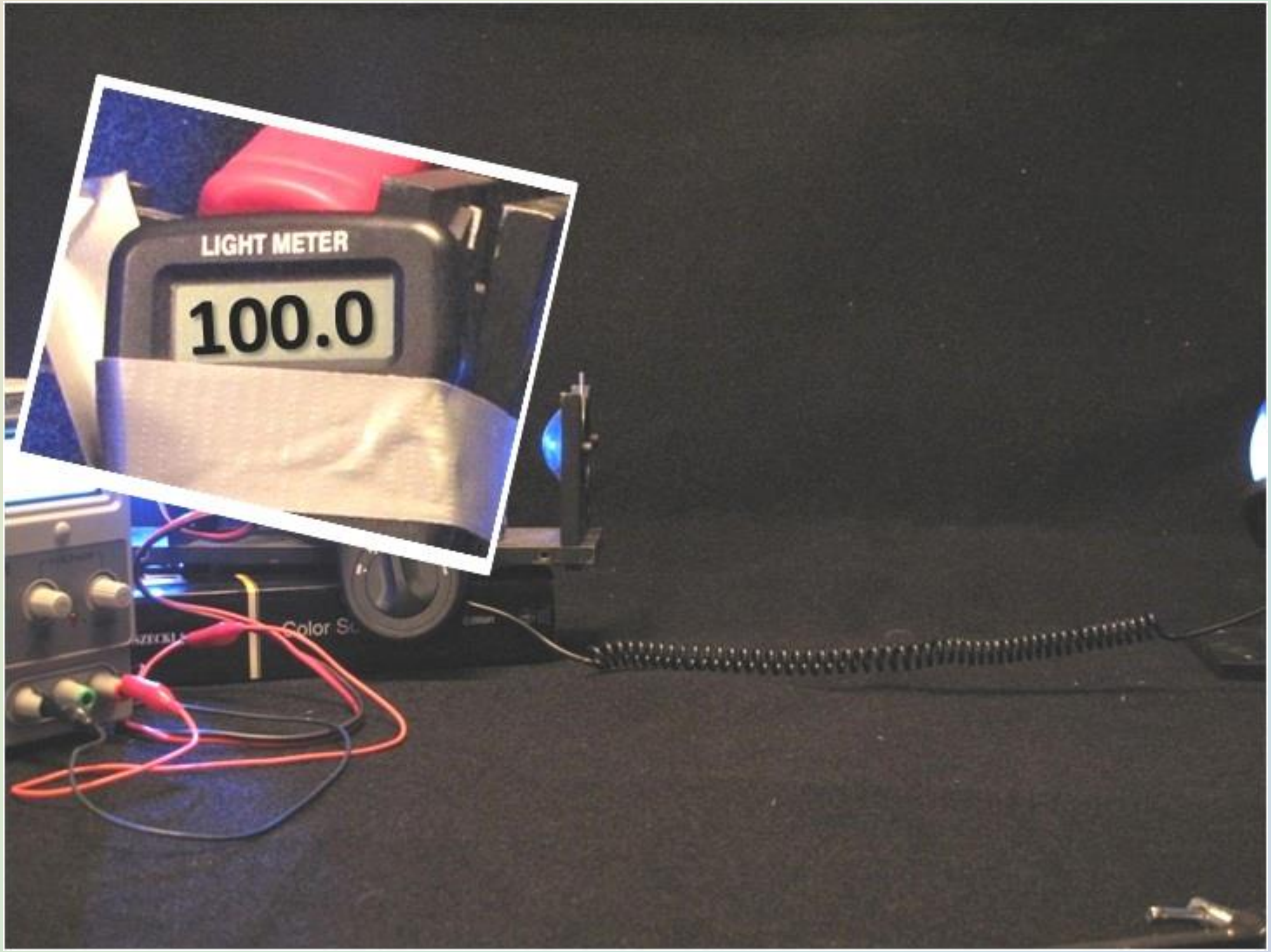
- Measure through complimentary filter
- Want to avoid gloss angle
- 45/0 geometry or 0/45
- Can report “density”

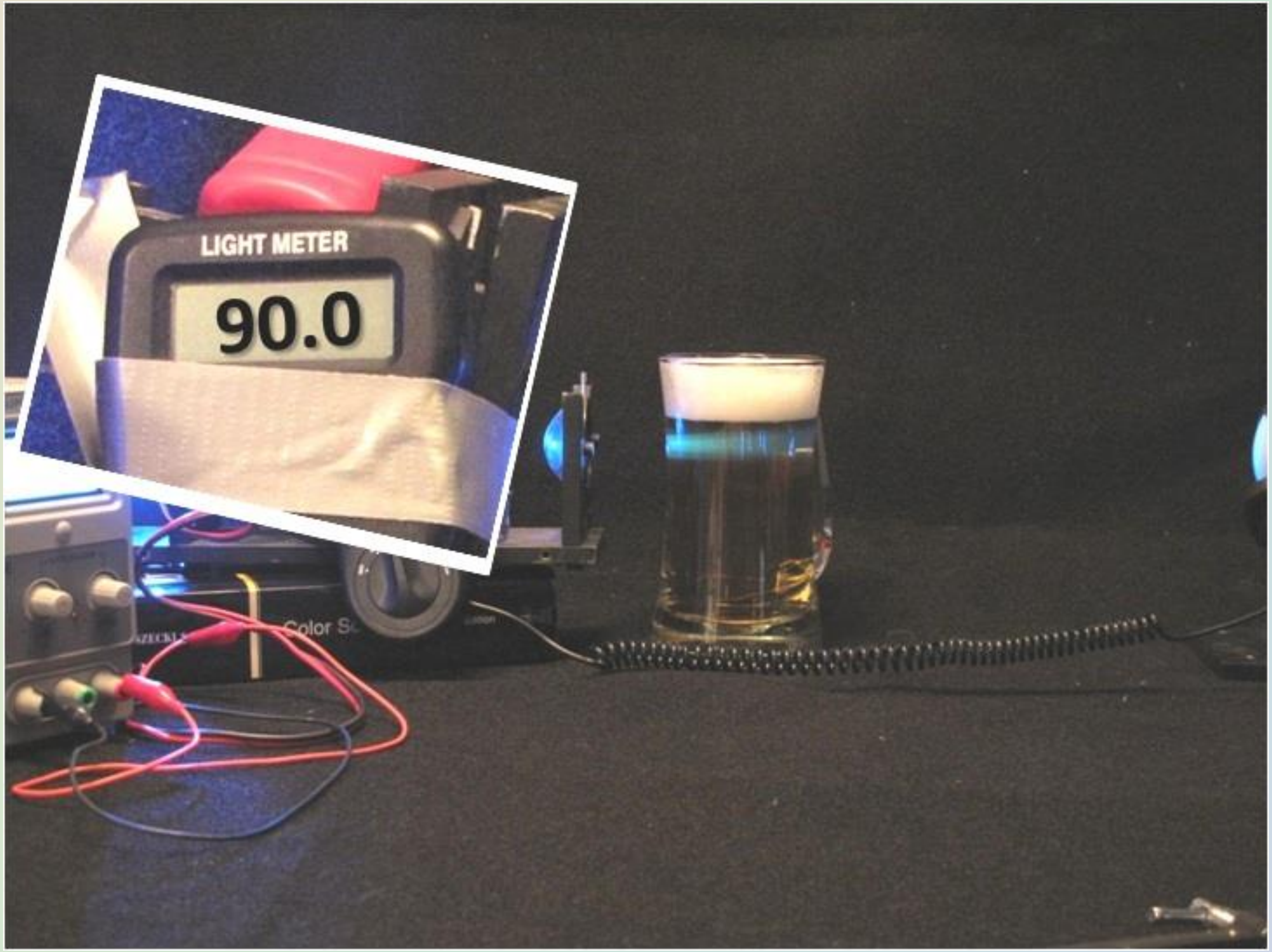


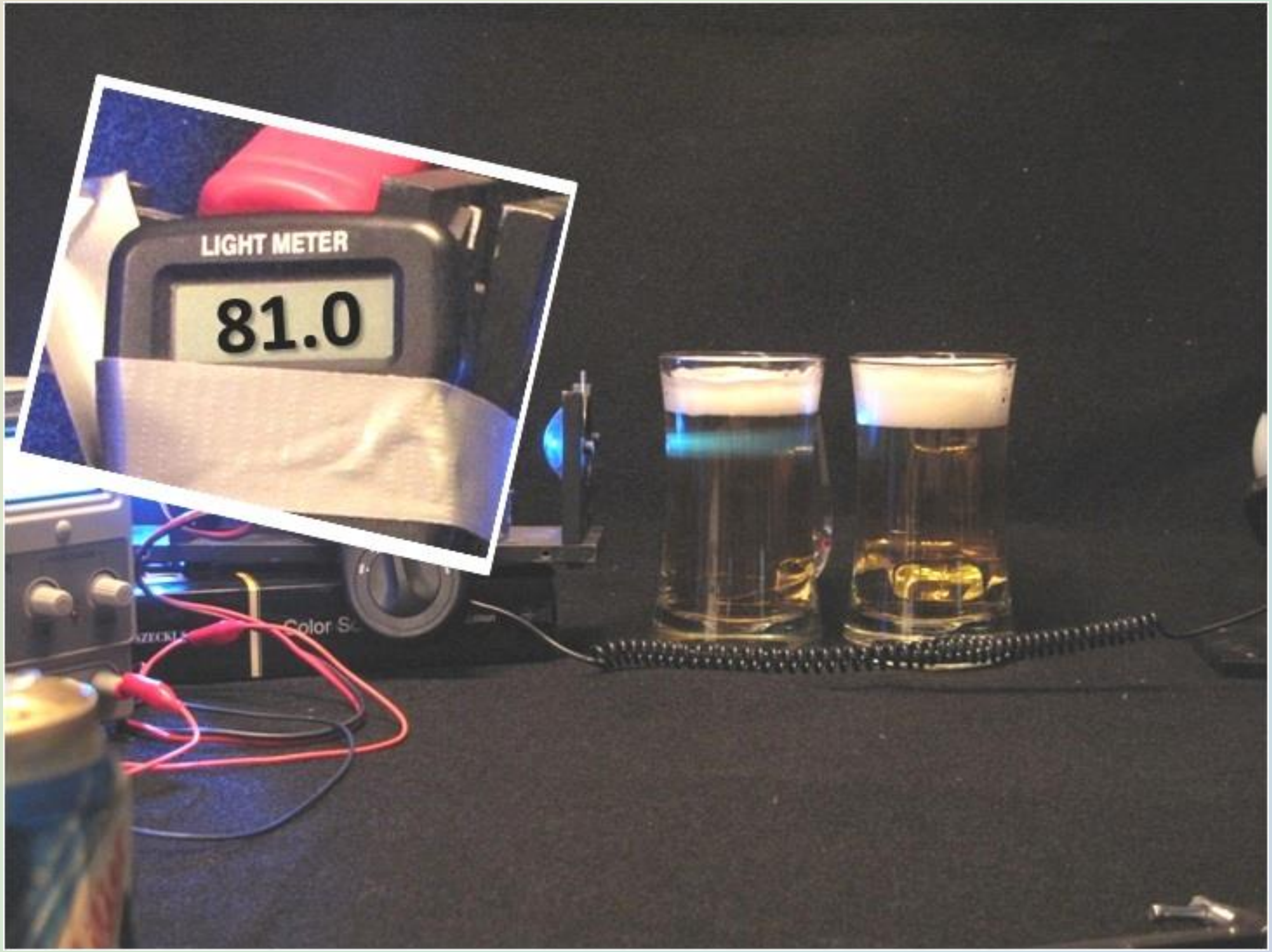
http://johnthemathguy.blogspot.com/2014/09/a-guide-to-reflectance-measurement.html

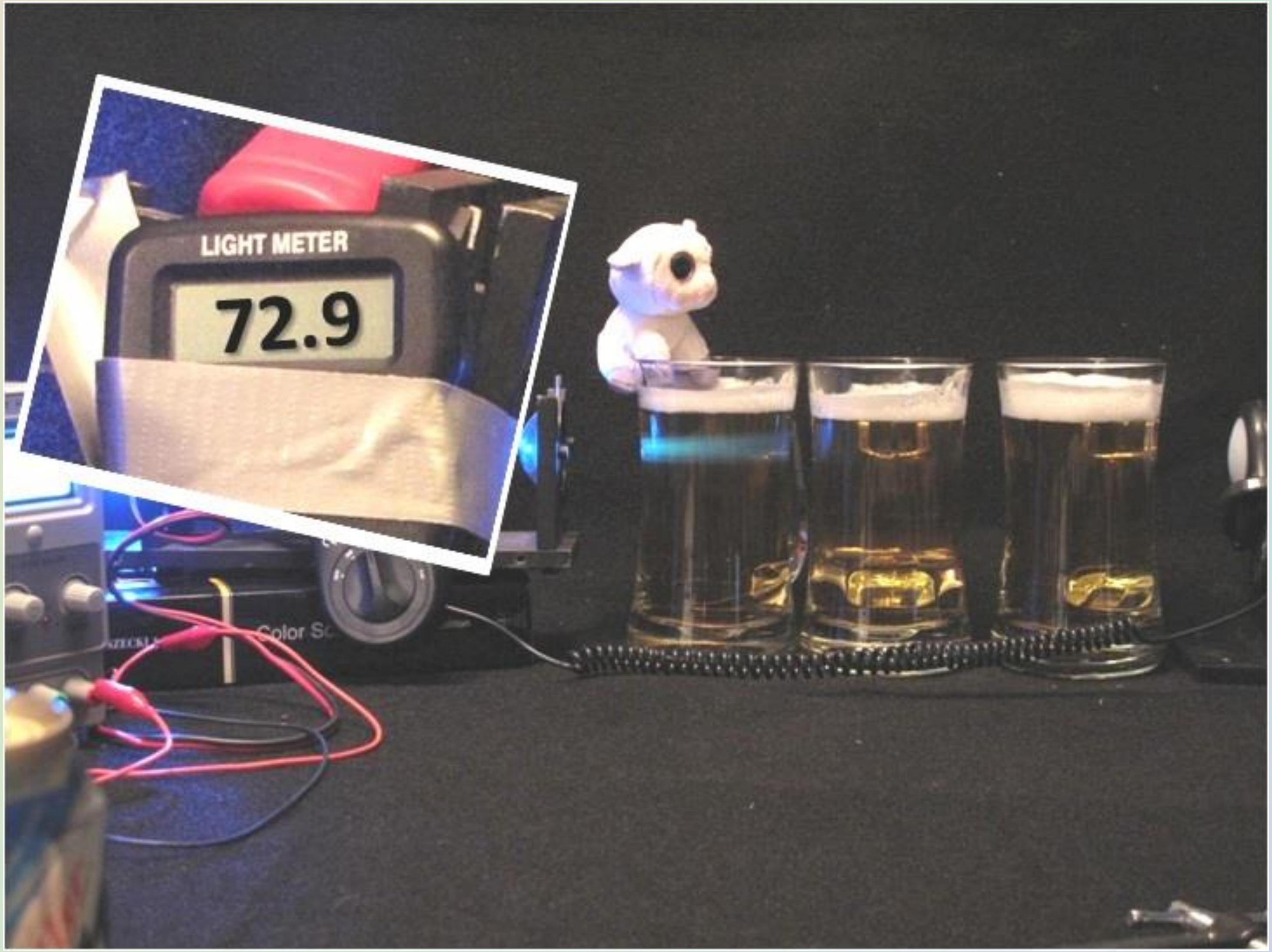
*First,*
*let’s talk about*
*Beer’s Law.*


DC POWER SUPPLY HY3003D
0.69
04.6
CURRENT
VOLTAGE
Color Science
Second Edition


LIGHT METER
100.0


LIGHT METER
90.0


LIGHT METER
81.0
Color Sc


LIGHT METER
72.9


http://johnthemathguy.blogspot.com/2012/08/one-beers-law-too-many.html

# Beer’s Law

- Amount reflected depends on ink film thickness
- … or pigment load
- Follows Beer-Lambert-Bouger Law
- Density is roughly proportional to ink film thickness

# I want to measure ink

- ISO 13655 mandates 45/0 or 0/45 for graphic arts

# I want to measure paint

- Paint is opaque
- No dependence on ink film thickness
- Kubelka-Munk equation
- Spherical (with specular) makes sense for paint formulation
    - Emulates viewing under diffuse lighting
    - What if viewed under directional lighting?

# I want to do QA on my formulation

- Paint, ink manufacturer, plastics masterbatch
- Not final product
- Not depend on surface structure
- Want to
  - exclude all specular (0/45 with polarizers)
  - Include all specular

# Obvious choice for paint

Non-contact

# Textiles

- Very rough surface, spherical works better
- What if you are *printing* on textiles?

# I want to measure decorating on cans

# I want to measure decorating on cans

- Coke (45/0) vs Pepsi (spherical)
- 45/0 – sensitive to position on round can
- Ink on aluminum, with and without whitener
- Spherical – not always correlated as well to perception

# I want to measure wet ink

- Newspaper presses – hot off the press is still wet
- As it dries, the surface gets rougher and the 45/0 color changes
- Cross-polarized filters remove all the specular

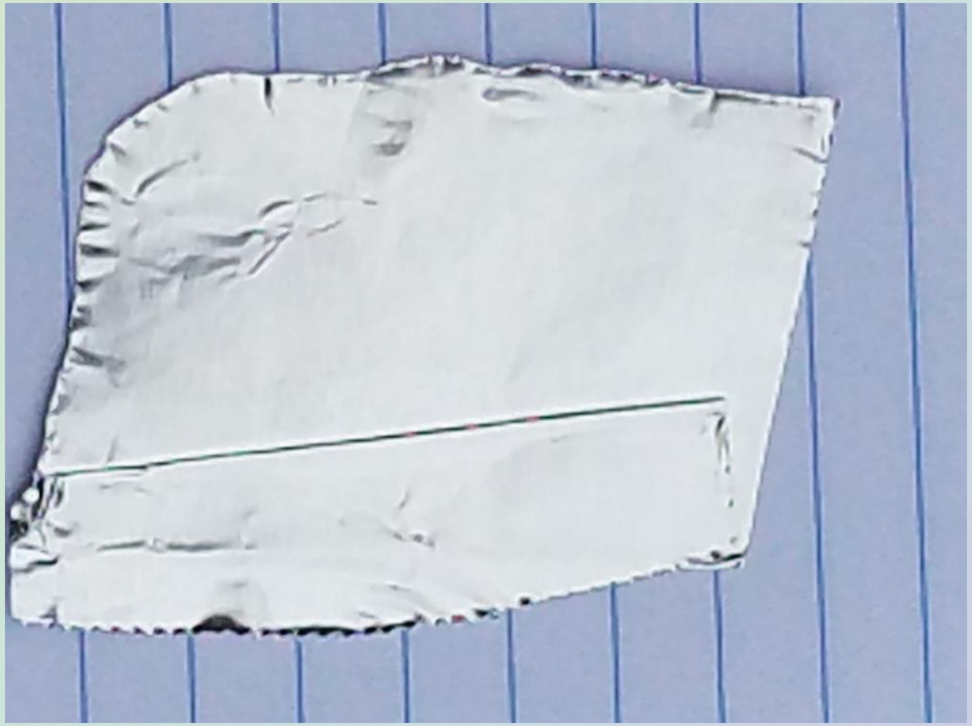
http://johnthemathguy.blogspot.com/2014/09/a-guide-to-reflectance-measurement_24.html

# I want to measure metallic luster


http://johnthemathguy.blogspot.com/2014/09/measuring-metallic-inks.html

# I want to measure metallic luster

Directional Lighting



Diffuse Lighting

# Part 5

*How many D65s*
*in a $2^o$ observer?*

http://johnthemathguy.blogspot.com/2014/11/how-many-d65s-are-there-in-2-degree.html

# Choice of illuminant

# Color depends on lighting

# Color depends on lighting

# Important point

*Computation of CIELAB emulates*
*what the object looks like*
*under a specific illumination*

# Choices for illuminant

- D65 – recommended by 8 out of 7 dentists
- D50 – mandated in the graphic arts
- Also D55, D75
- Illuminant A – tungsten, 2856K
- Illuminants B (4900K) and C (6800K)
- Illuminants FL1, FL2, ... FL6 - standard fluorescent lights
- Illuminants FL7, FL8, and FL9 - broad band fluorescent lights
- Illuminants FL10, FL11, FL12 - narrow band fluorescent lights

# Choices for illuminant

*What about LEDs!!?!?!?*

# Choice of “observer”

- $2^o$ or $10^o$ observer

# Choice of “observer”

# The wonderful thing about standards

- Illumination type
  - D65
  - D50, etc
  - Illuminant A
  - F1 – F11
  - LEDs
- Observer
  - $2^o$ versus $10^o$
  - Age related yellowing

# Part 5

*Sensor technology*

# Types of measurement devices

- Filter based
  - Densitometers
  - Colorimeters
  - Spectrophotometers
- Grating based

# Detector

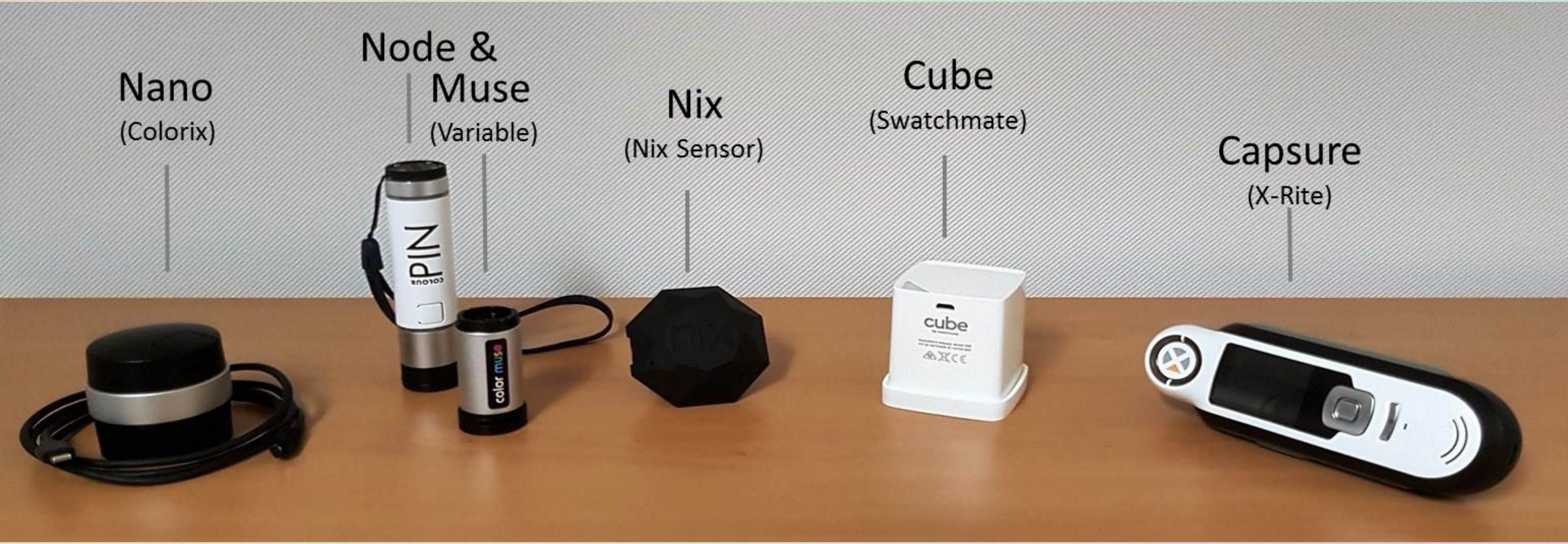
- Choices
  - RGB camera
  - Colorimeter
  - Spectrophotometer

# Detector – RGB Camera

**Measure color with an RGB camera**

http://johnthemathguy.blogspot.com/2014/07/rgb-into-lab.html

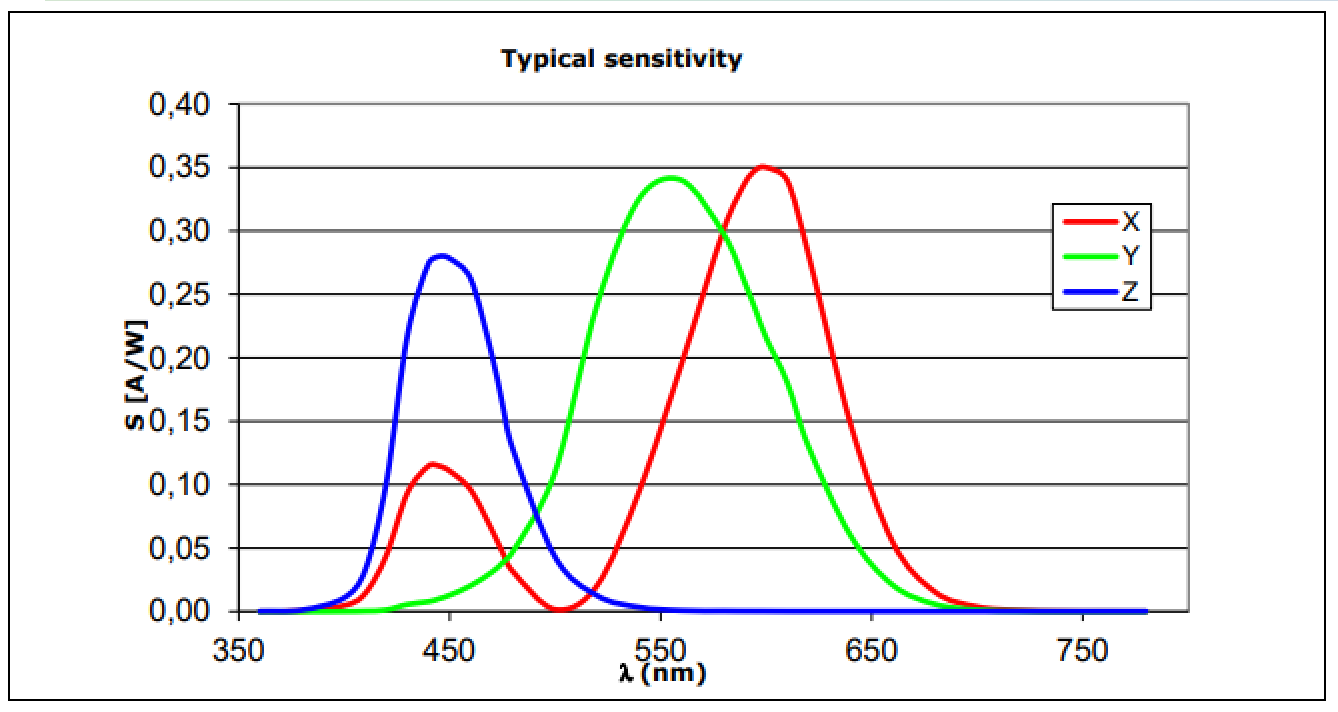
# Detector - Colorimeters




https://www.coltechcon.com/publication/yes-they-arrived-cheap-affordable-ways-to-measure-color-an-explanation/

# Detector - Colorimeters

MAZeT MTCSiCT



# Detector - Colorimeters

*"If you are contemplating using a colorimeter as part of your color quality assurance project, I would recommend investing in a good set of dice. Your results will be just as good, and you will be able to play craps at lunchtime."*

http://johnthemathguy.blogspot.com/2017/07/of-colorimeters-and-spectrophotometers.html

# Detector

- Choices
  - RGB camera
  - Colorimeter
  - Spectrophotometer
  - Don’t trust the color
  - Selecting color
  - QA

# Thank you for staying awake!

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http://johnthemathguy.blogspot.com/