Computer Graphics: Color I

Part 2 – Lecture 10

Today's Outline

- Colors in the Real World
- Interaction of Light with Materials
- Human Perception of Light

COLORS IN THE REAL WORLD

Electromagnetic Radiation: Waves

Physics theories of light:

1. waves (classical mechanics)
2. particles (quantum mechanics)

wavelength, λ

frequency = cycles/sec.

frequency * wavelength = speed of light

$f * \lambda = c = 3.0 \times 10^8$ m/sec

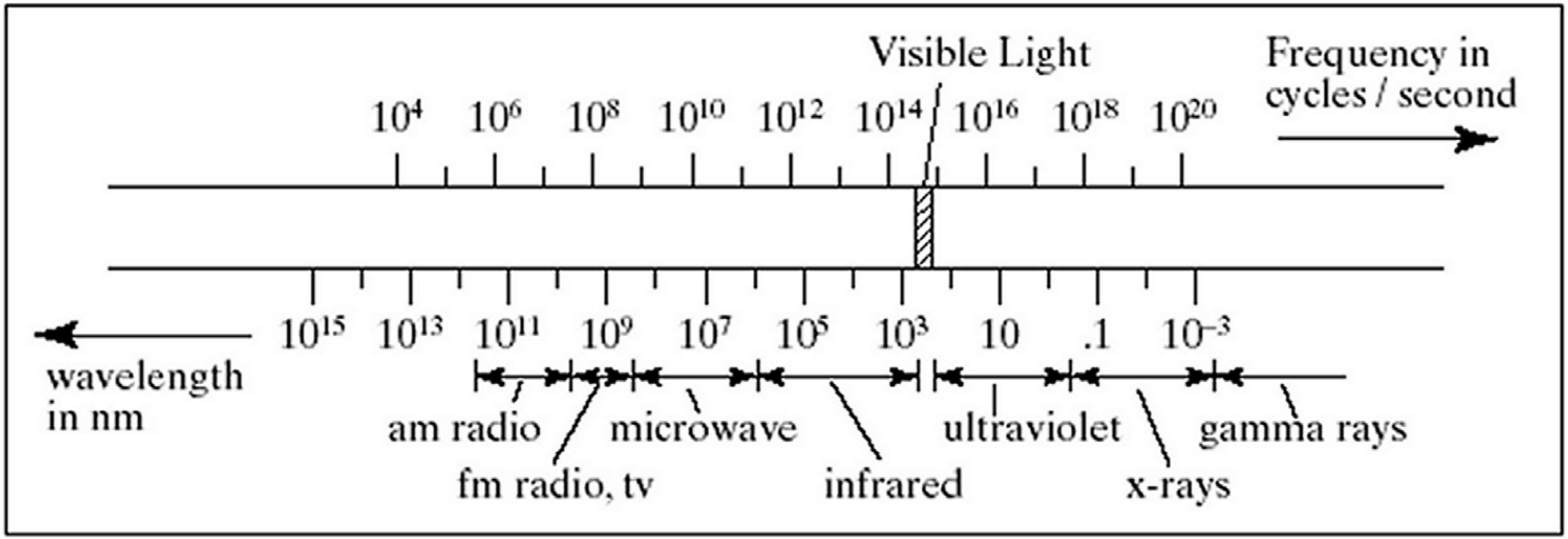
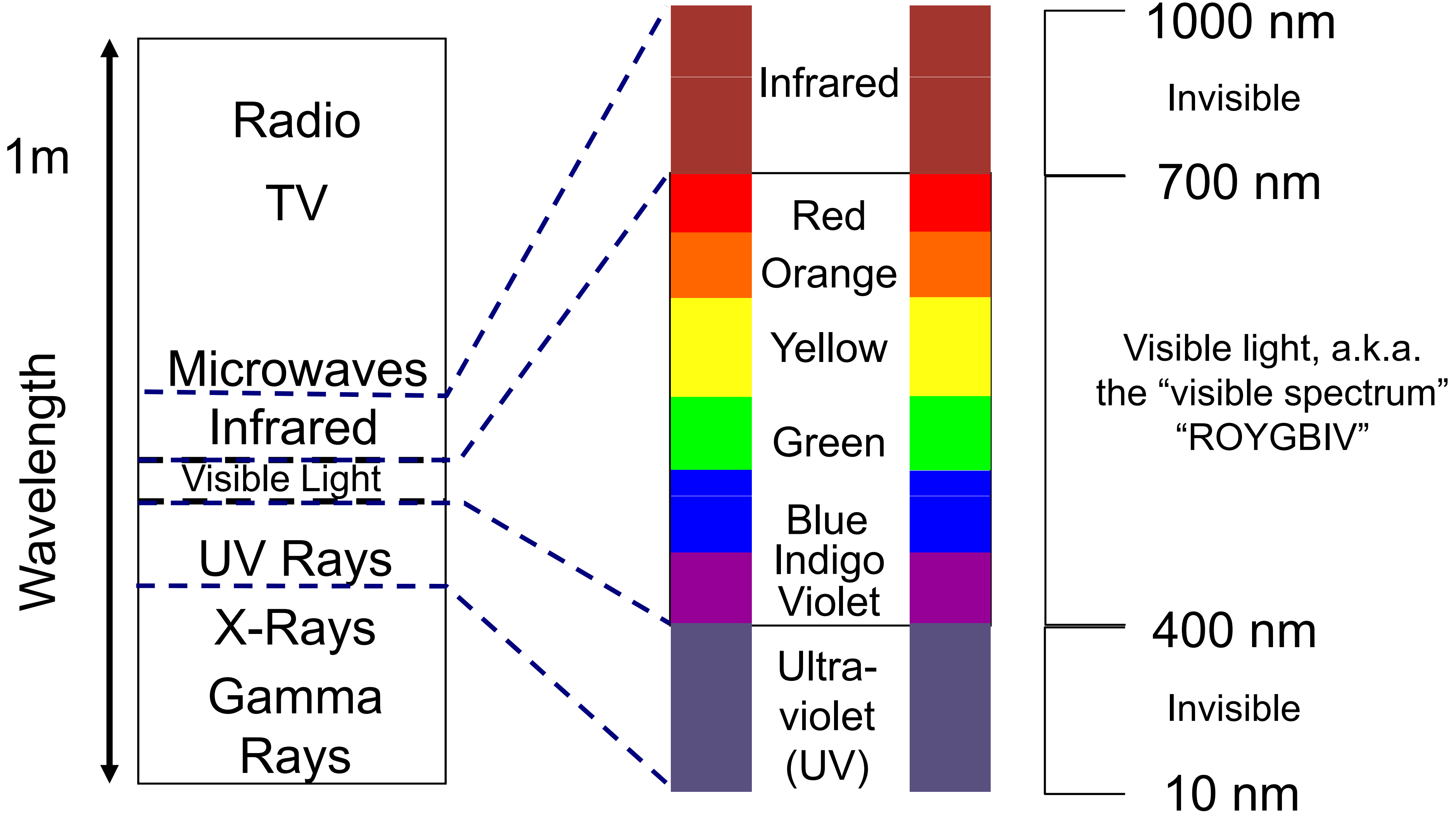


FIGURE 12.1 Electromagnetic spectrum.

Some Neighbors of Visible Light

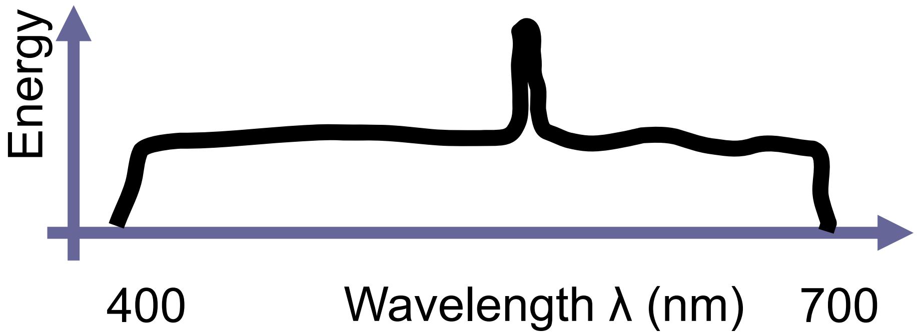


Spectral Density Function (SDF): S(λ)

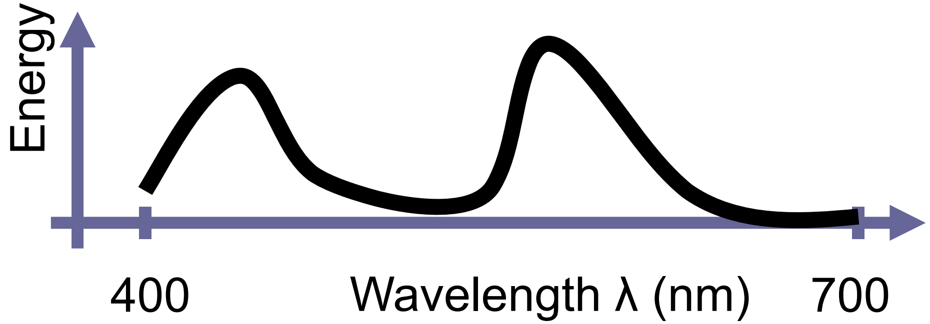
- S(λ) = power / unit wavelength = energy

spike or “single” wavelength
= “<u>spectral colour</u>”

uniform white/gray light



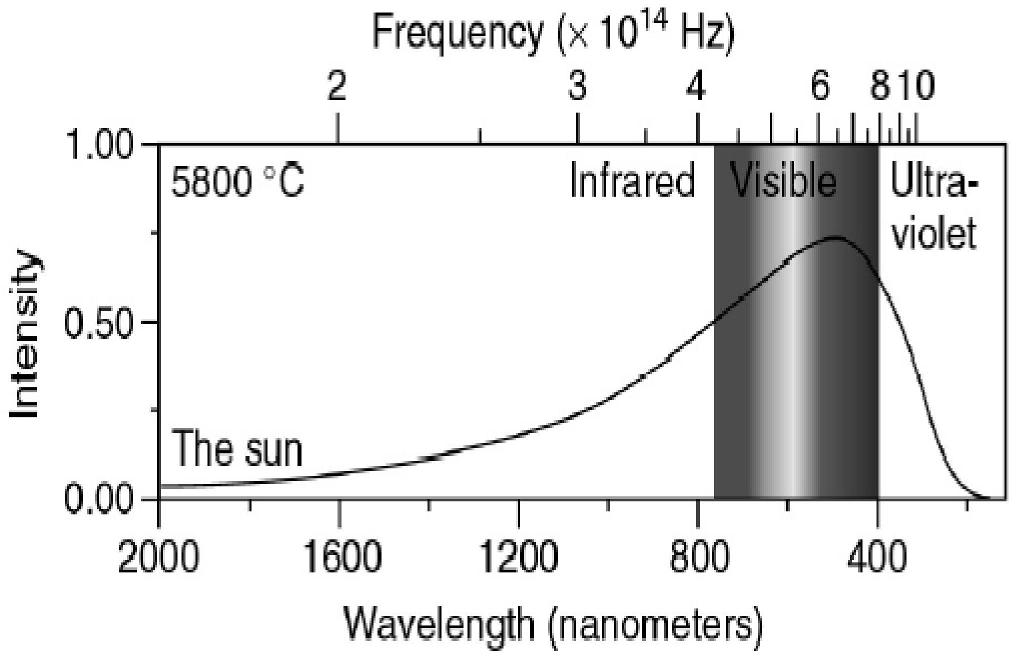
white light plus a dominant wavelength



arbitrary SDF: blue plus orange/yellow

SDFs for Different Light Sources

Some other light spectra: sunlight, tungsten lamp, fluorescent lamp



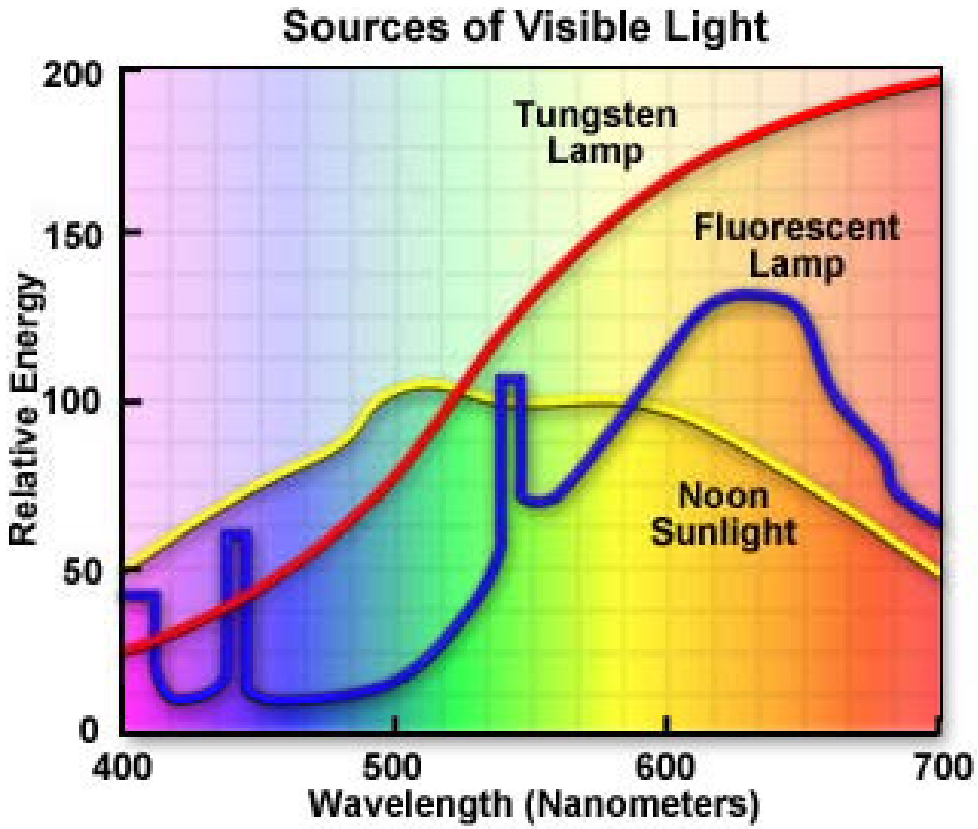
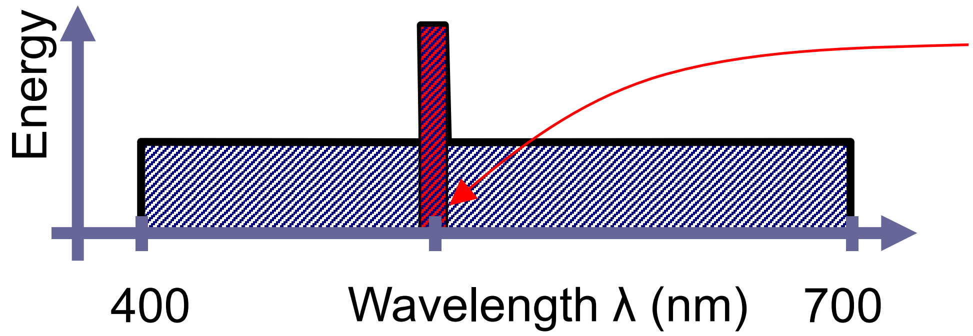


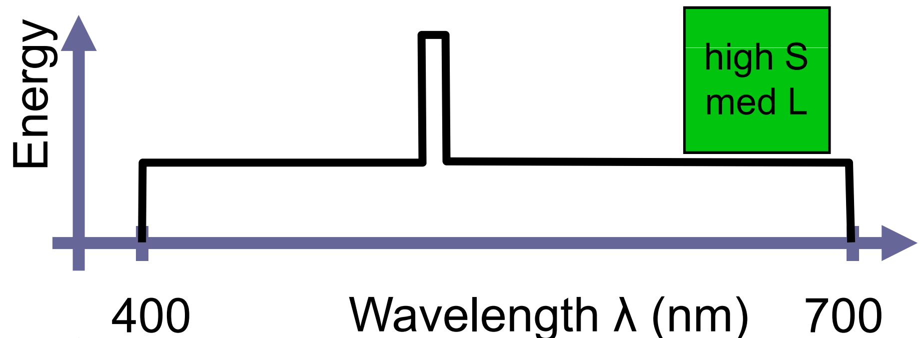
Figure 2

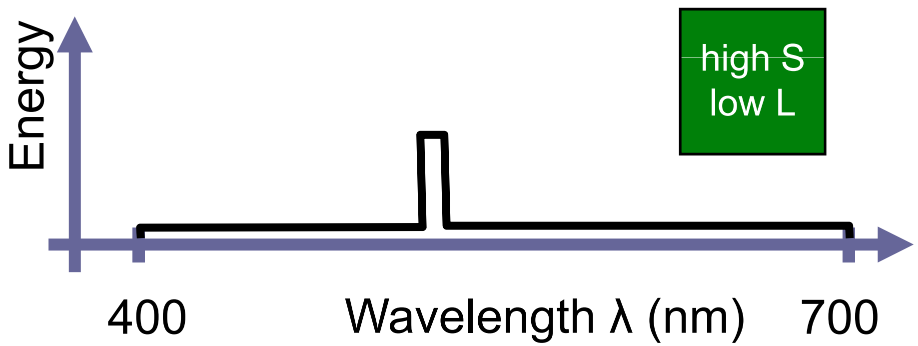
http://www.micro.magnet.fsu.edu/optics/lightandcolor/sources.html

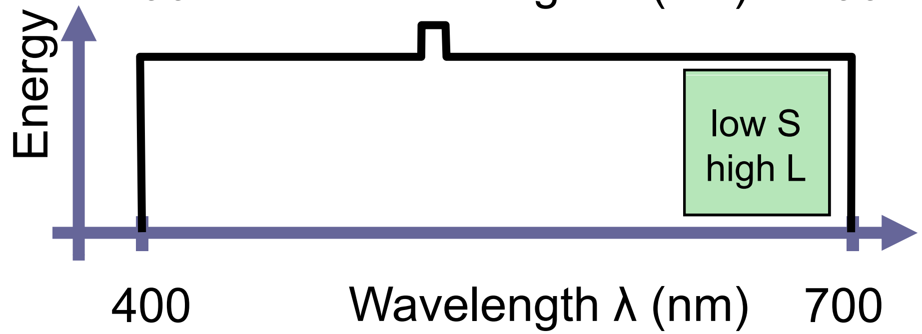
Describing Colors using the SDF

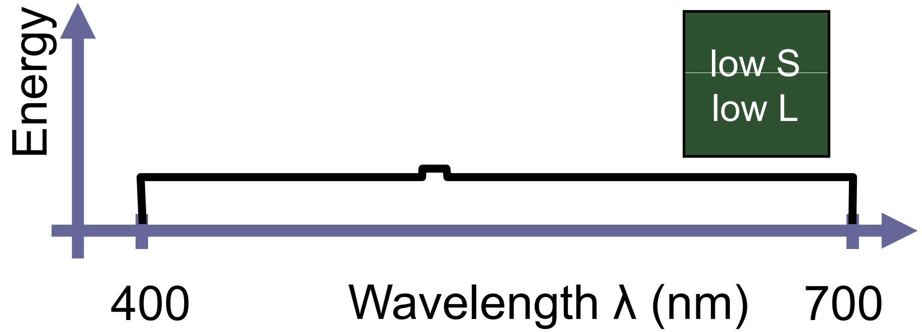


- **<u>Hue</u>**: dominant wavelength
- **<u>Luminance</u>** (brightness): total power (integral of SDF)
- **<u>Saturation</u>** (also purity): % of luminance residing in dominant component









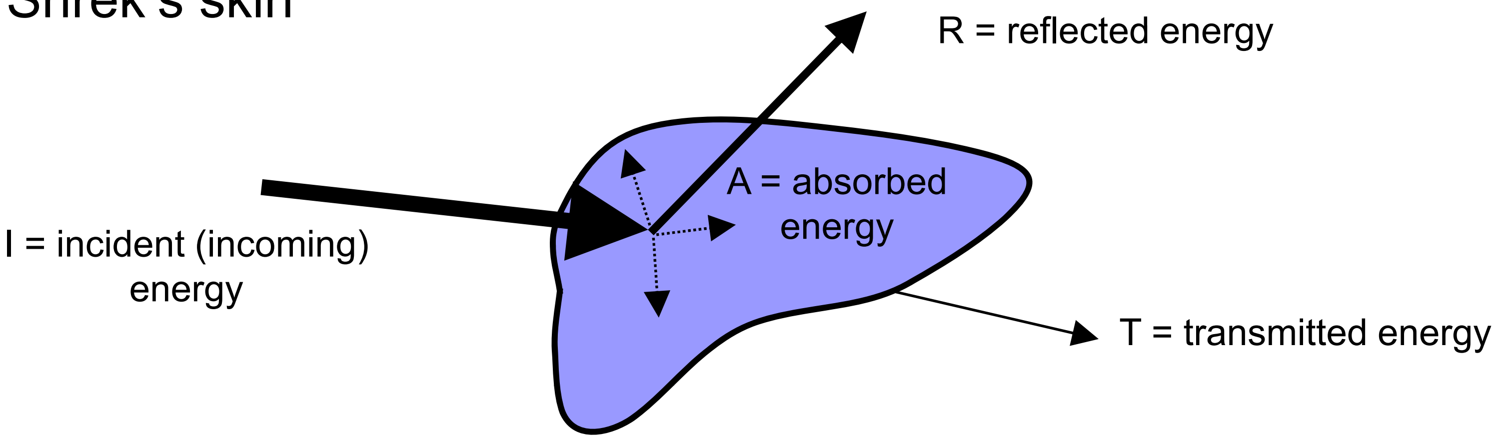
INTERACTION OF LIGHT WITH MATERIALS

Interaction of Light with Materials

Light ⇨ surface of some "body": 3 possible results

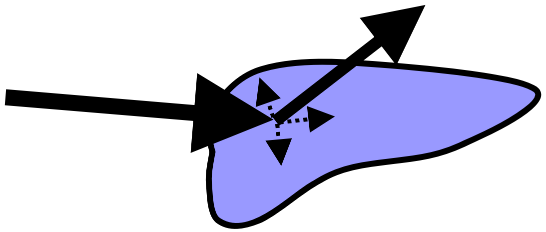
1. **Absorption** – energy of selected wavelengths retained within the body
2. **Transmission** – energy of selected wavelengths travels through and exits the body. Refraction of light occurs at boundaries.
3. **Reflection** – energy of selected wavelengths "bounces" off surface. Angle of reflection = angle of incidence.

- Also combinations of these 3, such as "internal reflection" when light enters a semi-translucent body, scatters, and some light reflects back out: human skin, Shrek's skin

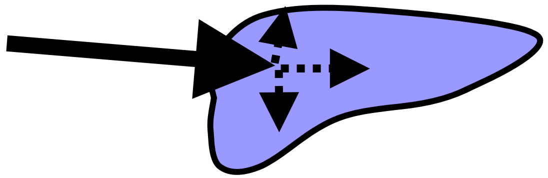


Interaction of Light with Materials

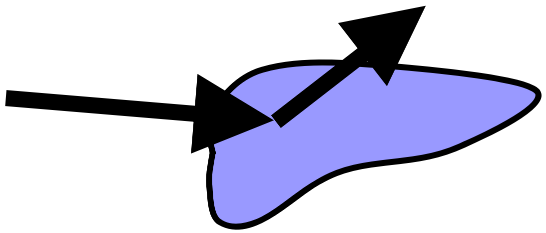
- Incident (incoming) light energy
  = absorbed energy + transmitted energy + reflected energy
  = retained + passed through + bounced off
- Chemical properties of the body determine the % of each.



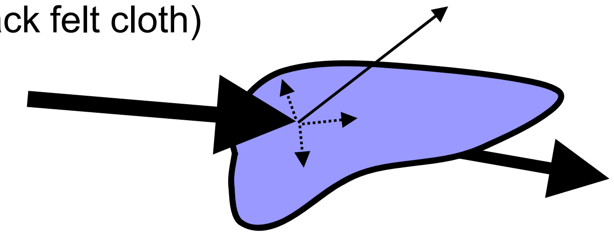
opaque coloured surface: A > 0 , T = 0, R > 0



opaque black surface: A = I ,T = 0, R = 0
(black felt cloth)



perfect mirror surface: A = 0, T = 0, R = I

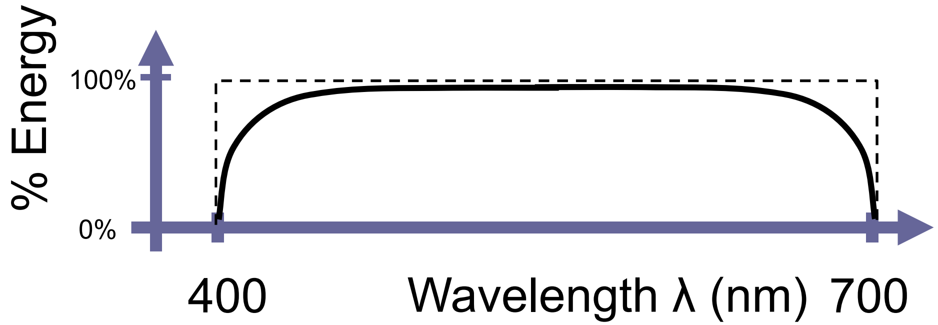


transparent surface: A, R small, T ~= I
(clear glass)

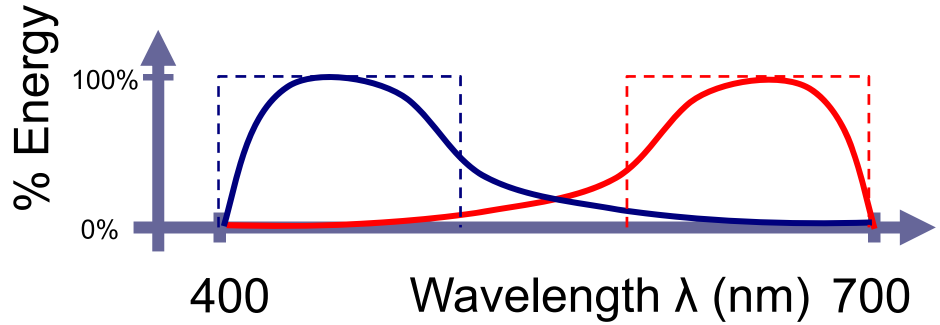
- Computer graphics: **<u>reflected</u>** (and refracted), **<u>transmitted light</u>**

Spectral Response Function (SRF)

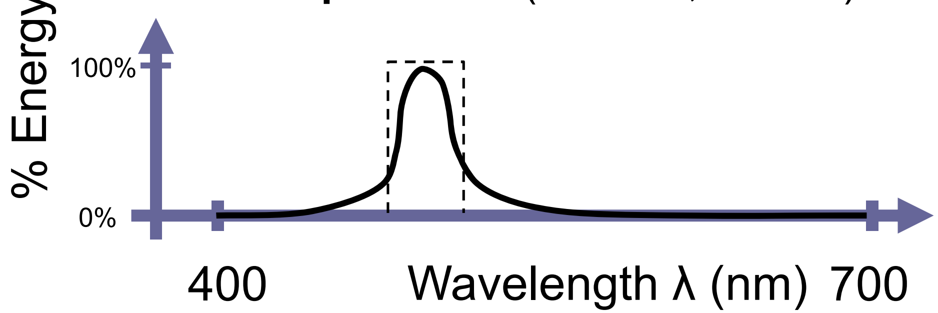
- Molecular structure of a body determines which wavelengths of light and what amount are absorbed, transmitted, or reflected
- Can be measured with a **spectral response function (SRF)** or filter function



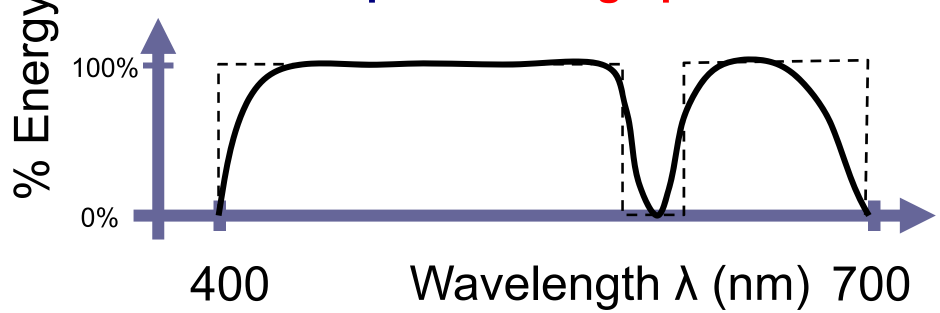
All pass filter (ideal ···, real —)



low pass and **high pass** filters



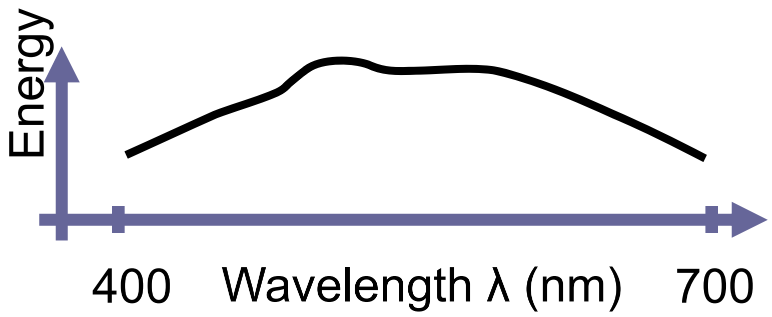
Narrow band filter



Notch filter

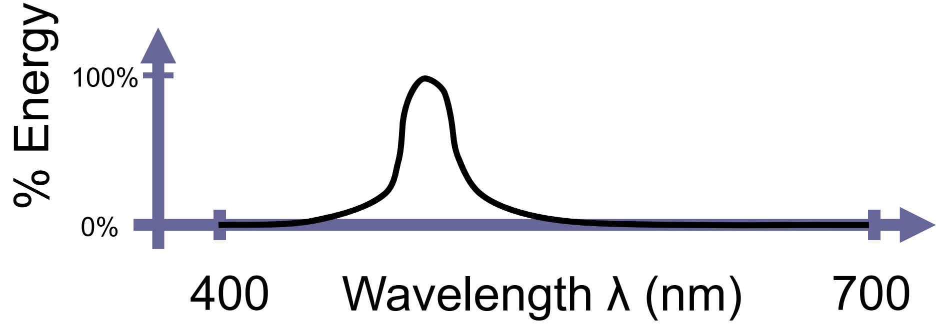
Light Source SDF x SRF = Result SDF

SDF of result = product of SRF and light source SDF
  i.e. at each wavelength, multiply SRF % times source energy



Sunlight SDF

x



Narrow band filter

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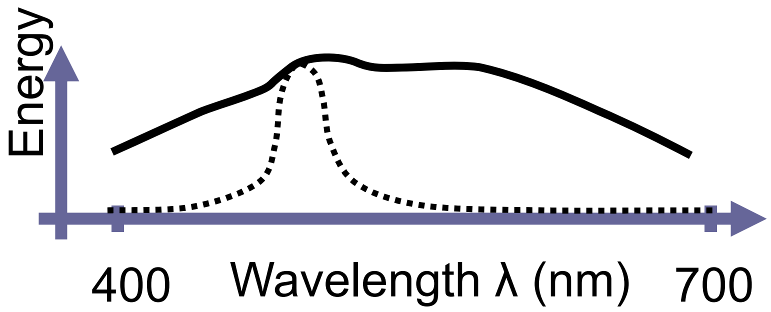

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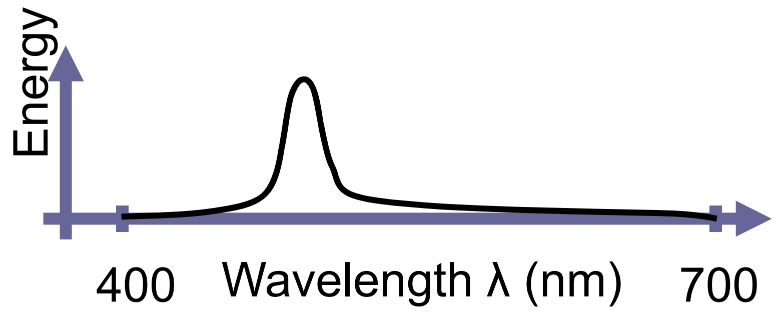


Filtered sunlight SDF

SDF x SRF = Result SDF

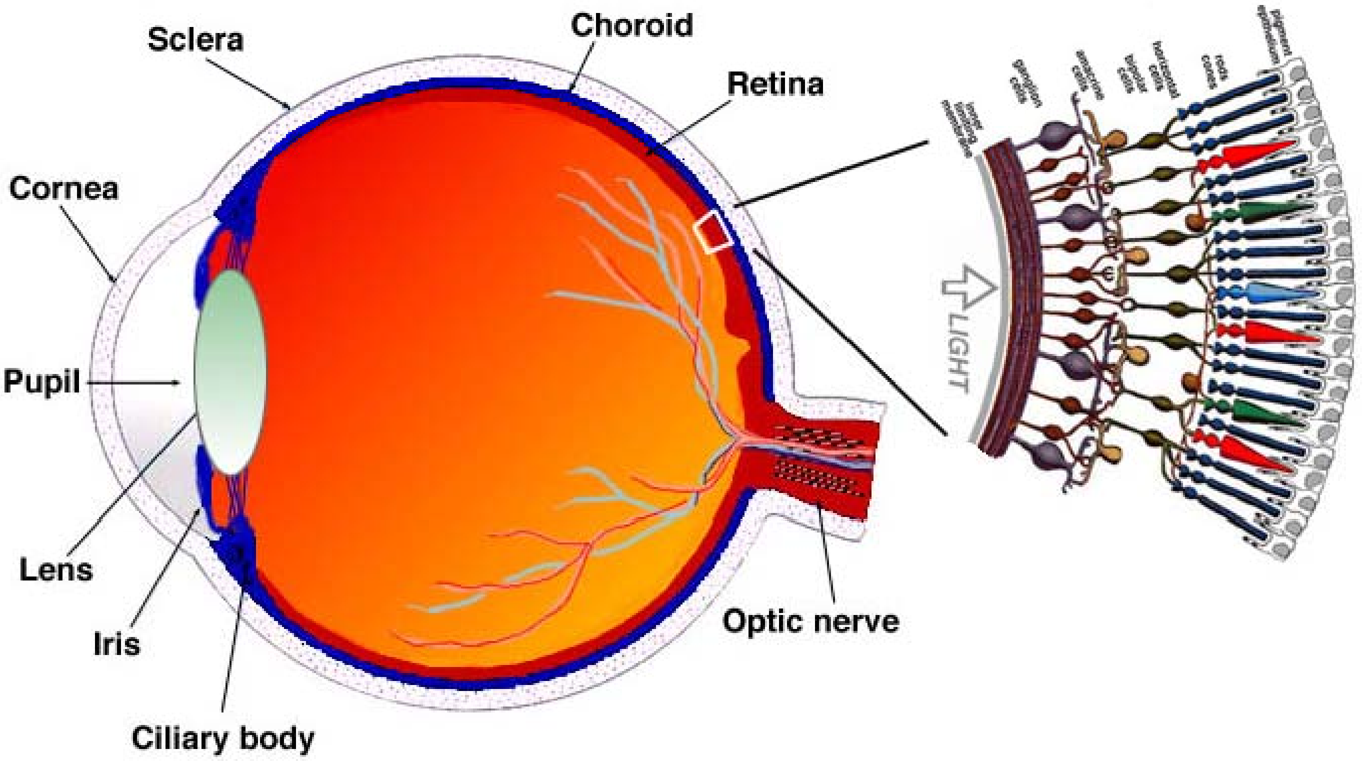
Why is this relevant for computer graphics?

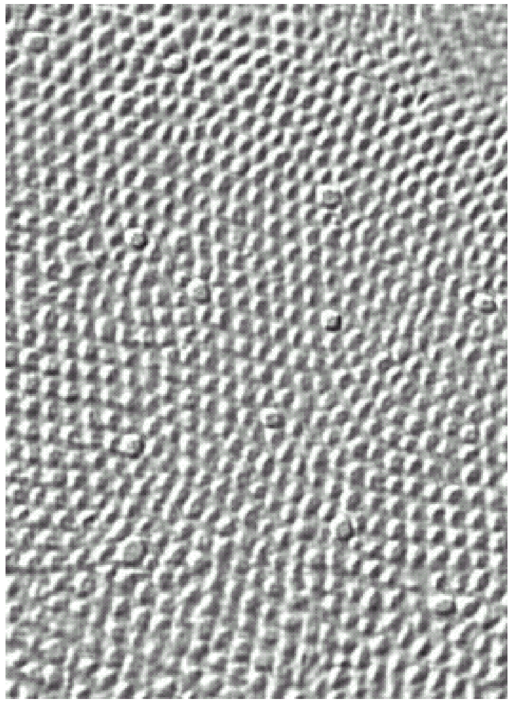
1. All light sources can be defined by their SDF
   - Natural light source: sun, fire
   - Artificial light source: light bulb, laser, LED, computer display
2. All light absorbers, transmitters, or reflectors can be defined by their SRF
   - Sensing devices: **absorbed light SRF**
     - Camera (digital photocell, film), human eye (retina)
     - Definition of “colour” =
       integral of (light source SDF × sensor’s SRF)
   - Glass, still water, cellophane: **transmitted light SRF**
   - Surface material of an object: **reflected light SRF**

HUMAN PERCEPTION OF LIGHT

The Eye

- Four types of receptors (sensors): R/G/B cones + rods, each has unique SRF

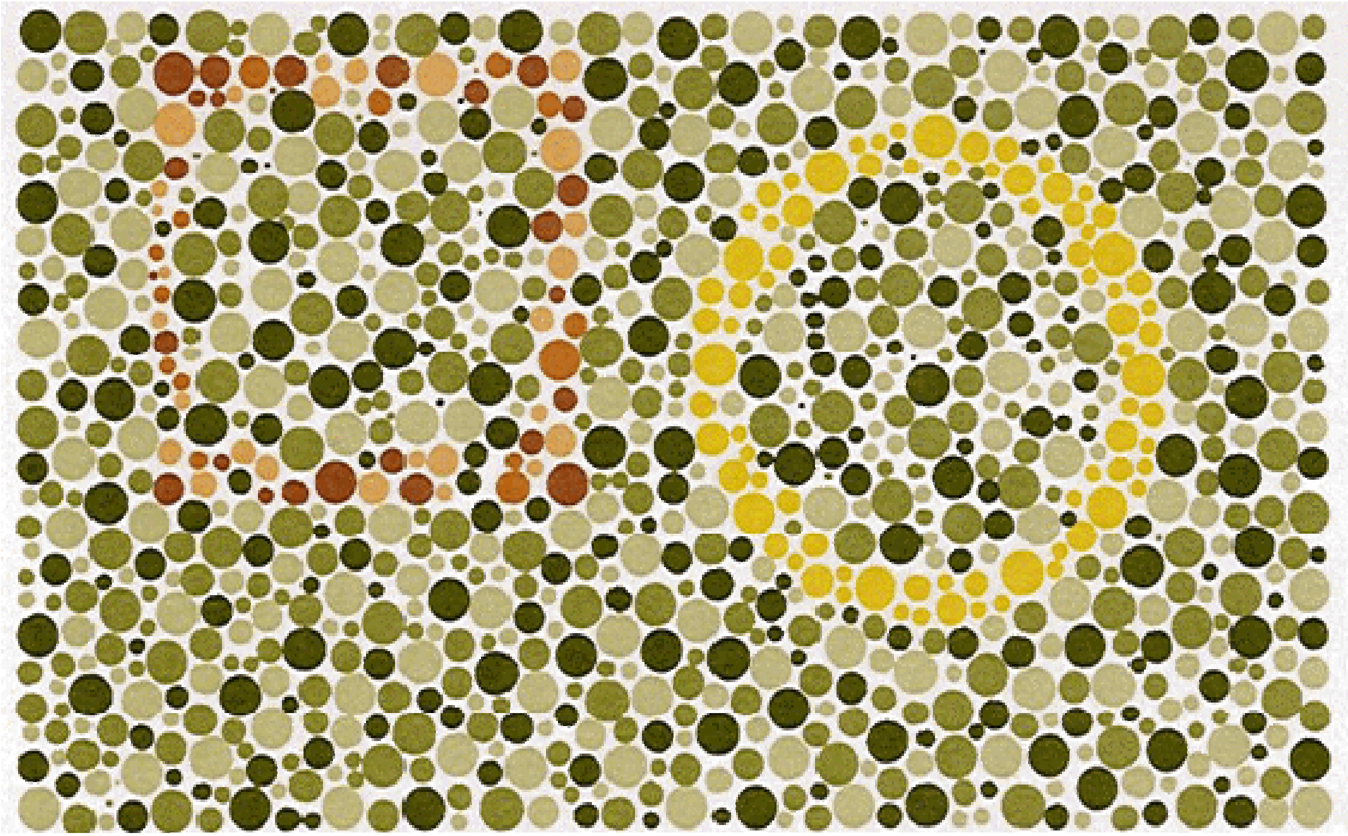




http://webvision.med.utah.edu/imageswv/fovmoswv.jpeg

http://webvision.med.utah.edu/imageswv/Sagschem.jpeg

Colour “Blindness”

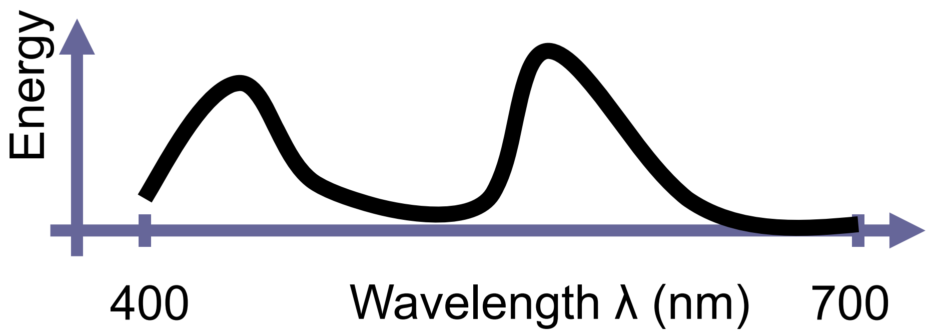


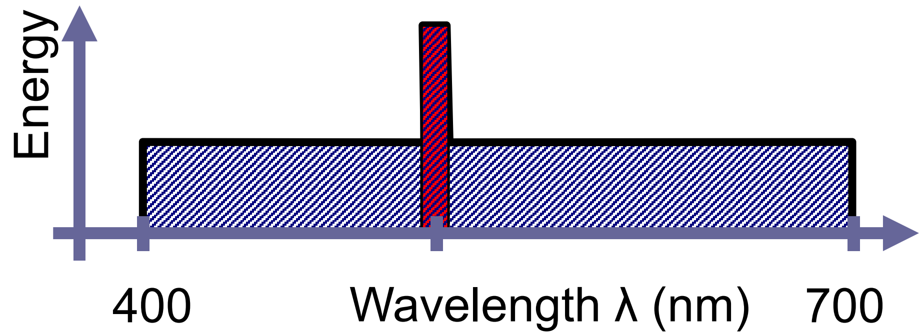
http://members.aol.com/protanope/card2.html

If you didn’t see both a yellow circle *and* a faint brown square, you are somewhat “colour blind” (in USA 5.0% of males, 0.5% of females). To find out more, visit: http://www.kcl.ac.uk/teares/gktvc/vc/lt/colourblindness/cblind.htm

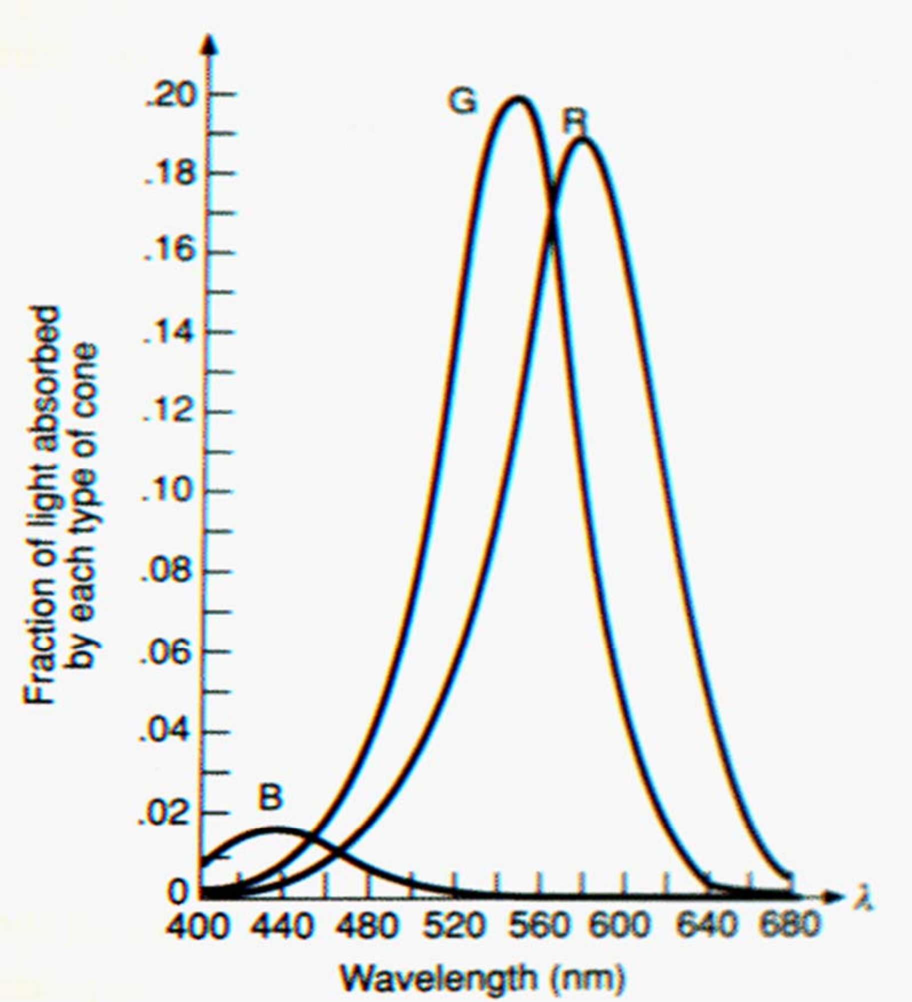
Colors and the SDF

- Many different SDFs are perceived by us as the same color!
- When describing a color (as seen by the eye) exactly, we do not need to know full SDF
- Three parameters are enough
- For example: just use hue, luminance and saturation



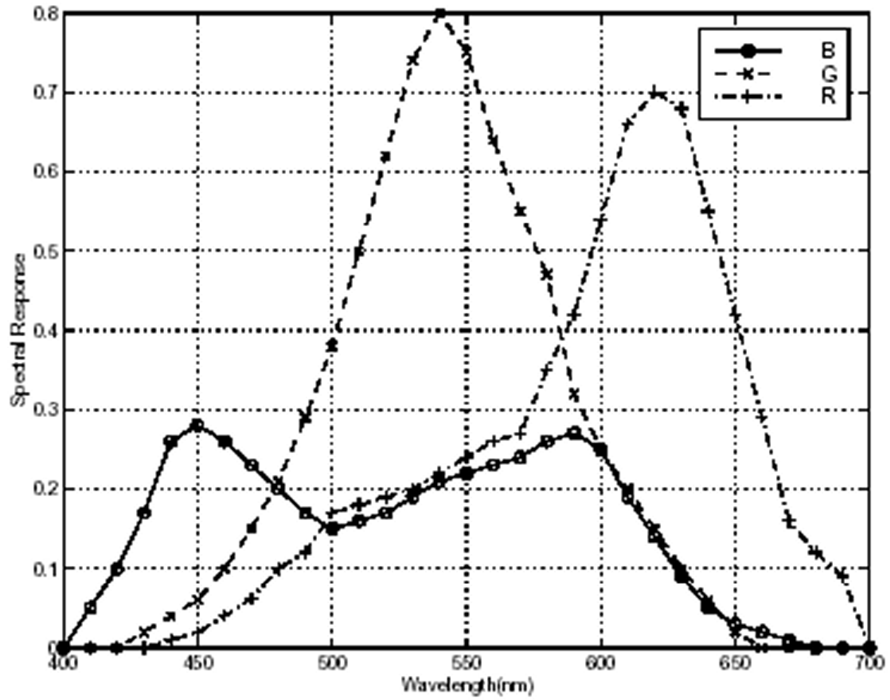


SRFs for the Eye and a Camera



http://www.ecs.csun.edu/~dsalomon/DC2advertis/AppendH.pdf

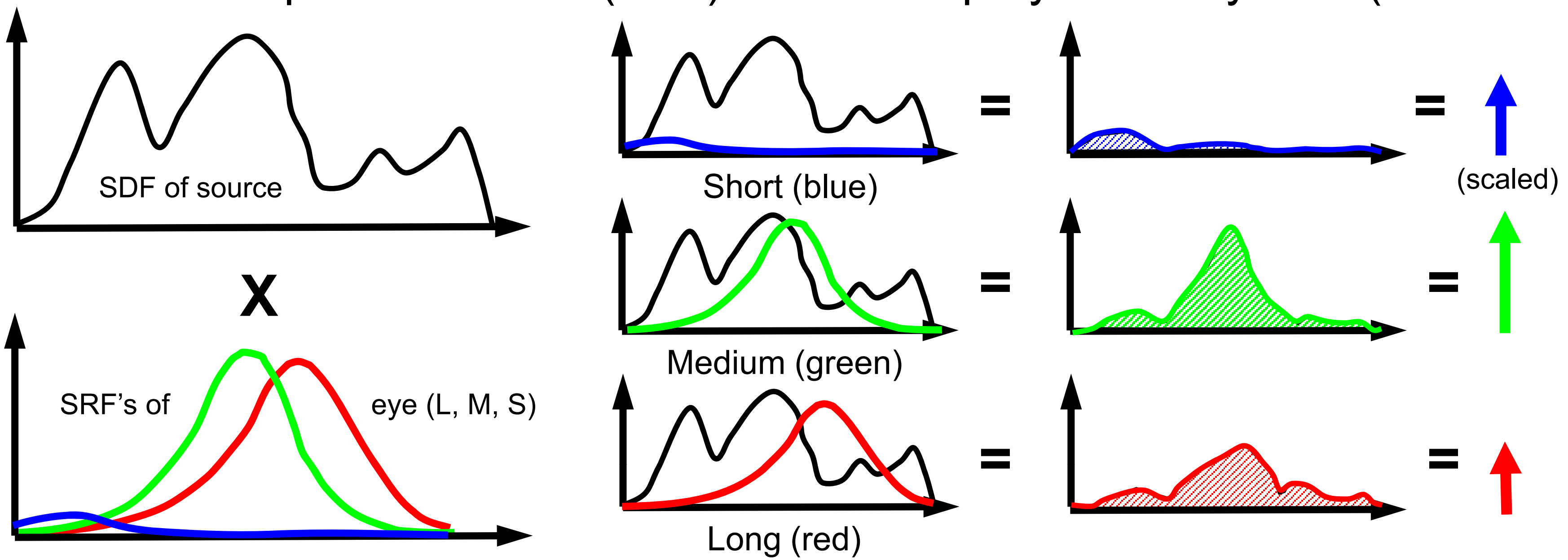
RGB spectral responses for a Kodak digital camera



http://www.stanford.edu/class/ee392b/handouts/color.pdf

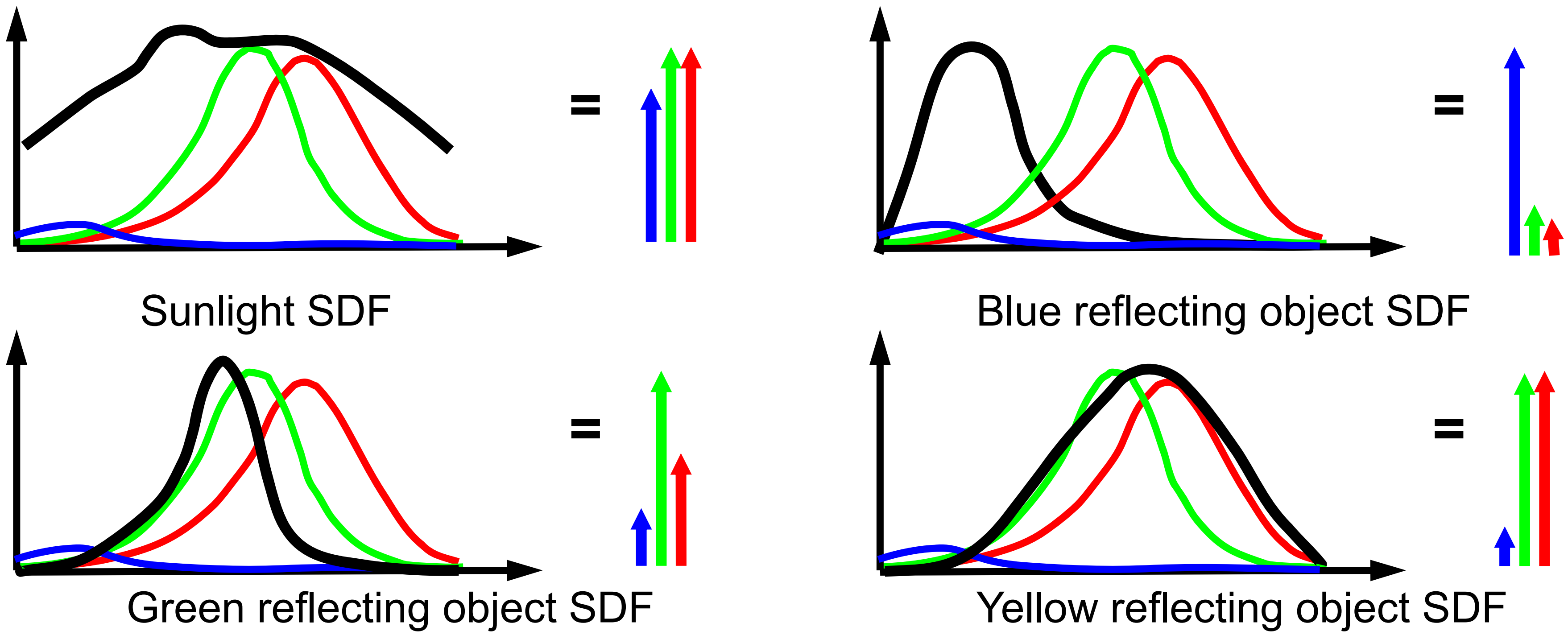
Seeing Red, Green and Blue

- A cone cell in the retina measures amount of red, green, or blue wavelength energy (3 SRF's). Responds only in bright light.
- SRF of a rod cell covers all wavelengths (measures "gray level" or intensity) Responds in low light, but not in bright light.
- Integral of R, G, or B cone response produces a single value
  Note: SRF's really L, M, S wave responses (long, medium, short), not R, G, B.
  Note: low response of short (blue) is scaled up by vision system (after retina).



Seeing Red, Green, Blue (cont'd)

- Example L, M, S responses for various SDF's



- Resulting L, M, and S SRF responses are independent values
- The 3 SRF response values are interpreted as hues by our brain, e.g. red + green = yellow, red + green + blue = white

SUMMARY

Summary

- **Spectral Density Function (SDF)**: describes the wave composition of light with power for each wave length segment
- **Spectral Response Function (SRF)**: can be used to specify how much % of each wave length are absorbed or reflected or transmitted
- Light with different SDFs can have the same color for our eye

References:

- Light and Colors: Hill, Chapter 11.1
- Dominant Wave Length: Hill, Chapter 11.2.1

Quiz

1. What is a spectral density function (SDF)?
2. In what ways can light interact with a material?
3. How can we describe this interaction?
4. What are hue, luminance and saturation?