

# Computer Graphics and Image Processing Color I

Part 1 – Lecture 5



# Today's Outline

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

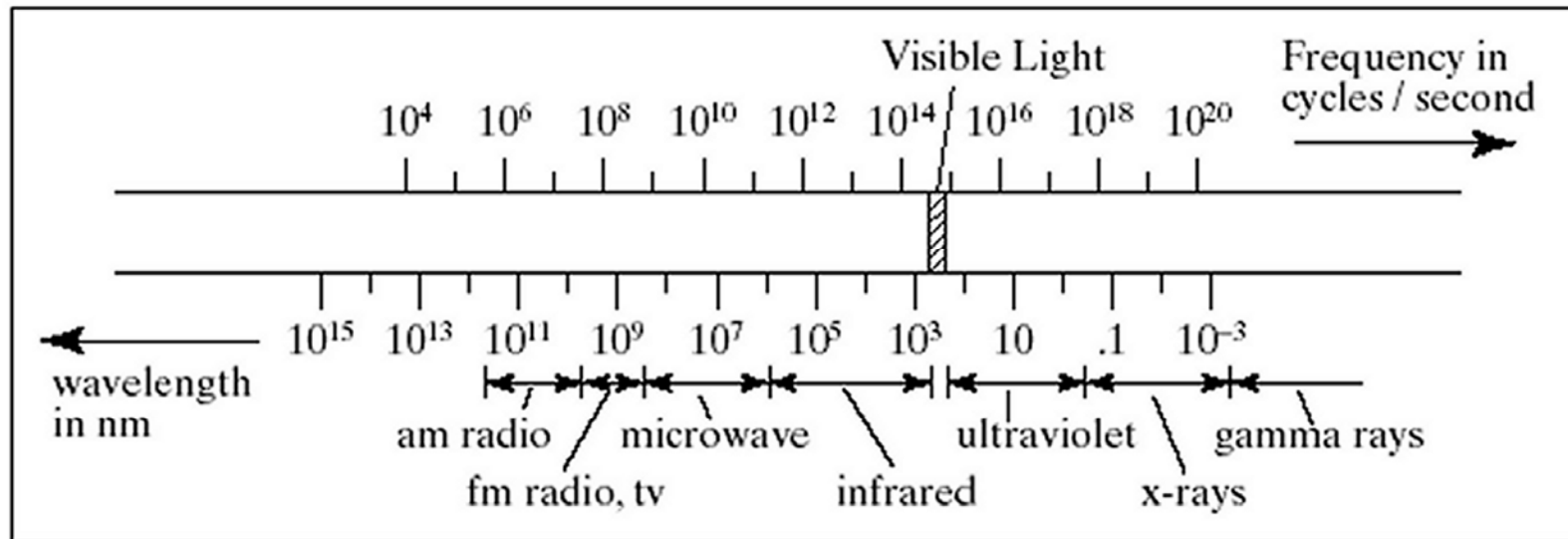
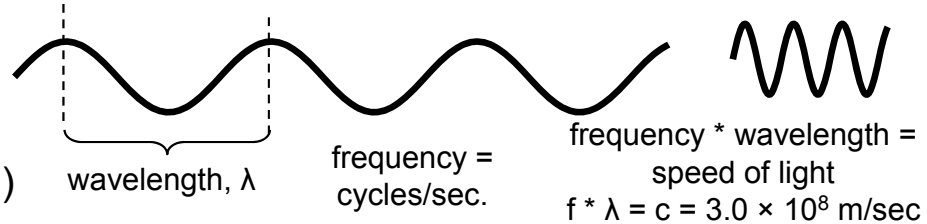


# **COLORS IN THE REAL WORLD**

# Electromagnetic Radiation: Waves

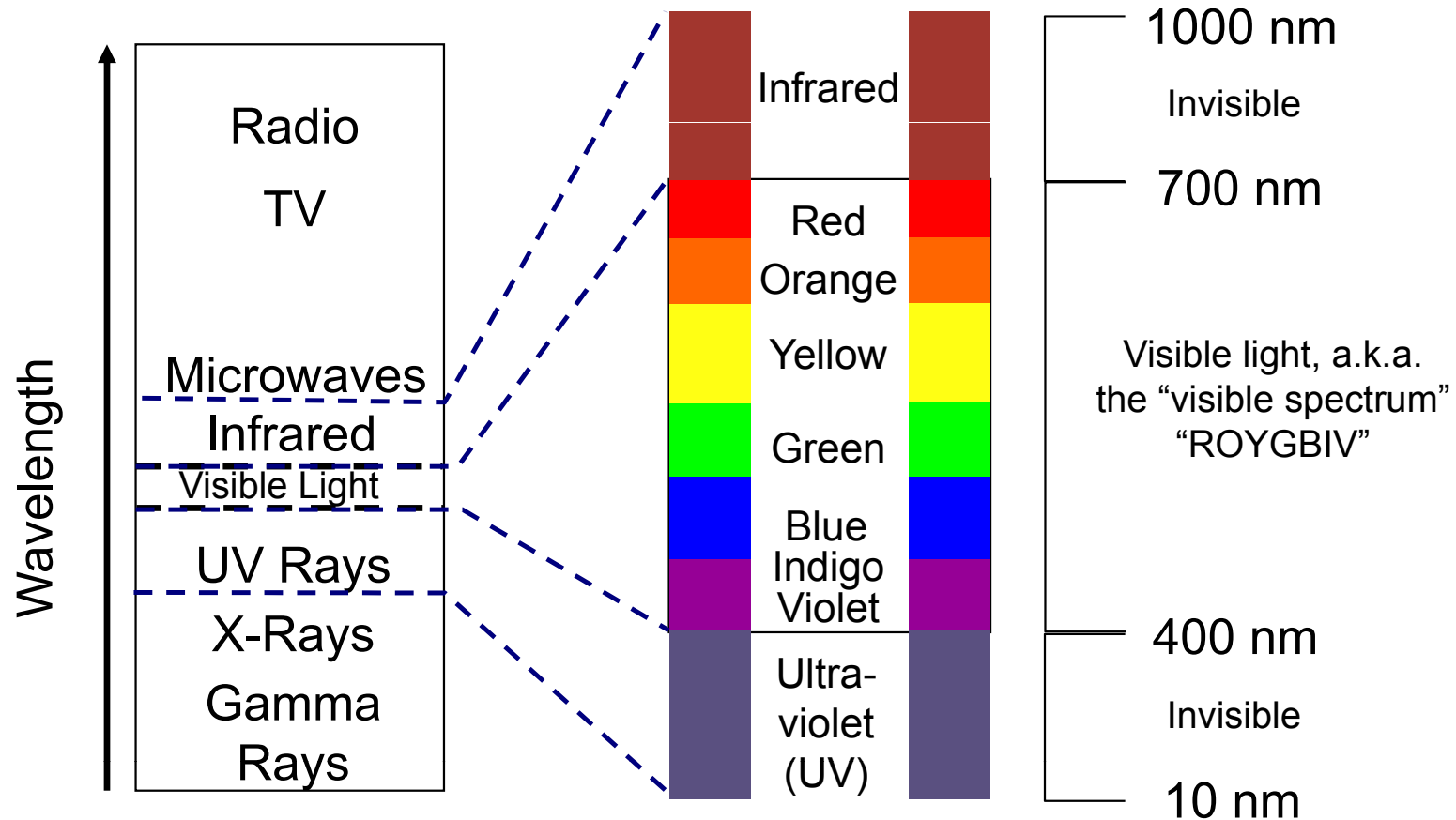
Physics theories of light:

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



**FIGURE 12.1** Electromagnetic spectrum.

# Some Neighbors of Visible Light



# Spectral Density Function (SDF): $S(\lambda)$

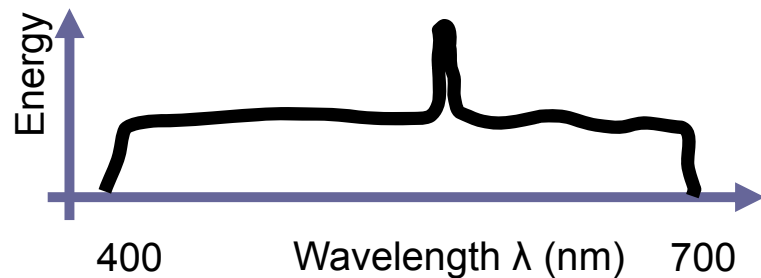
■  $S(\lambda) = \text{power} / \text{unit wavelength} = \text{energy}$



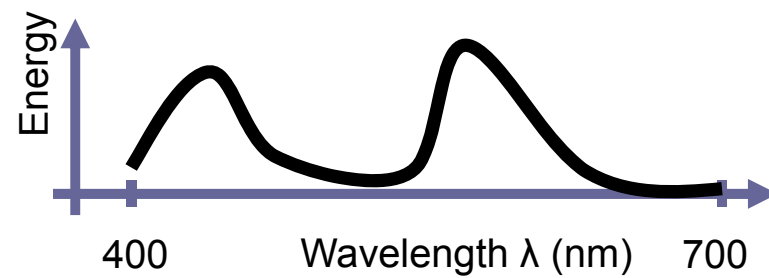
spike or "single" wavelength  
= "spectral colour"



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

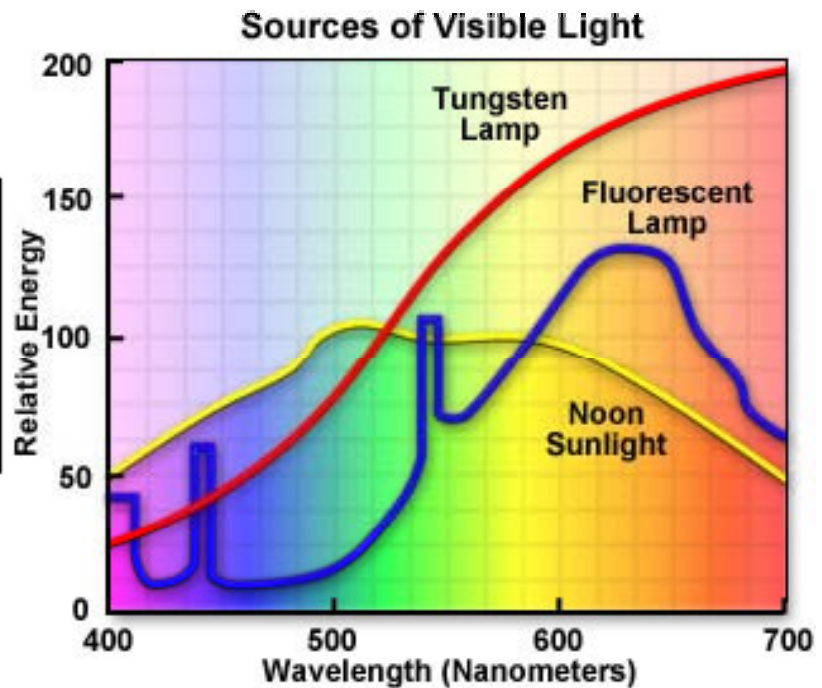
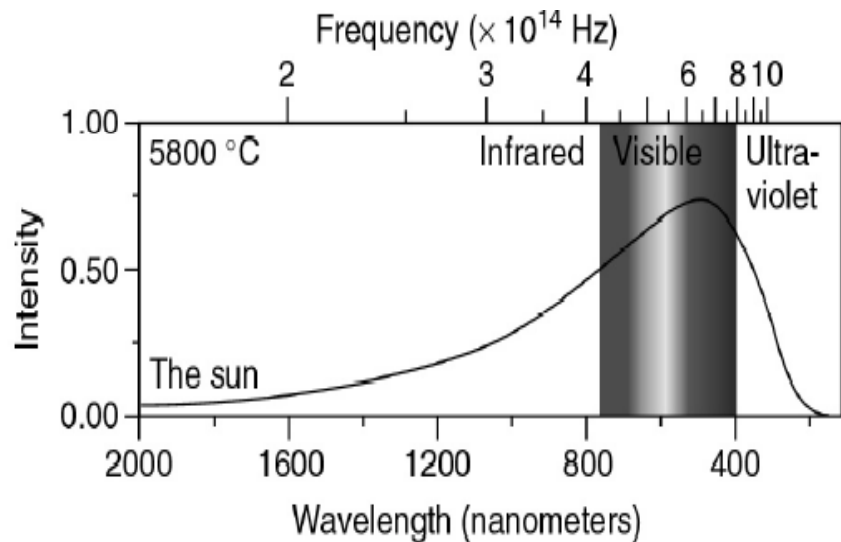
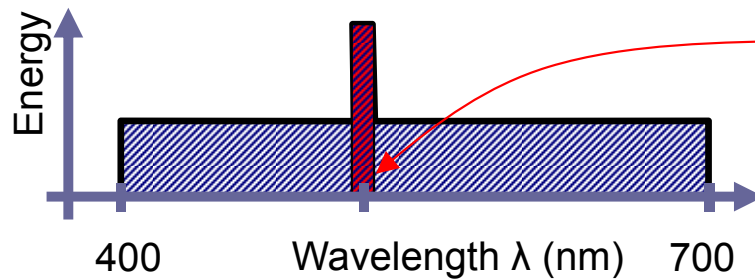





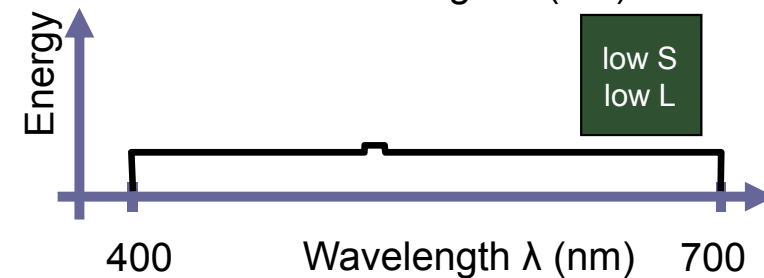
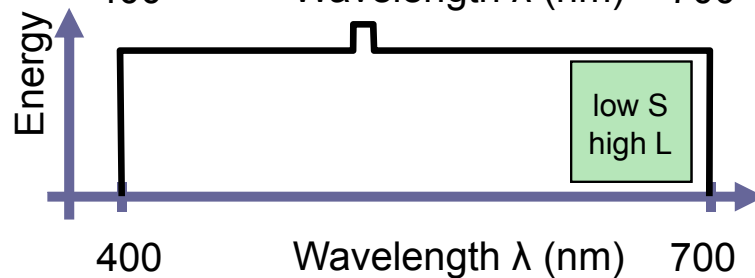
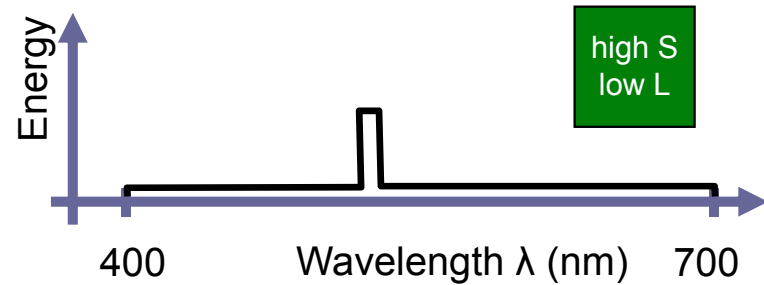
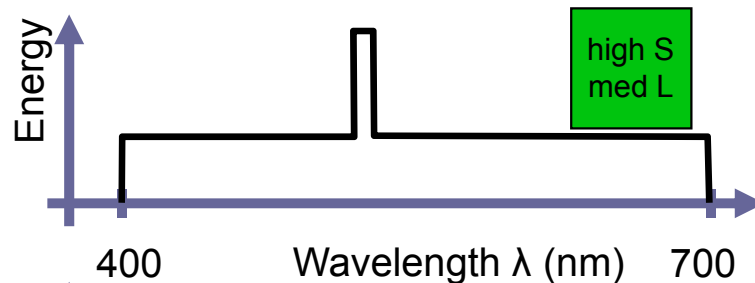
Figure 2

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

# Describing Colors using the SDF



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



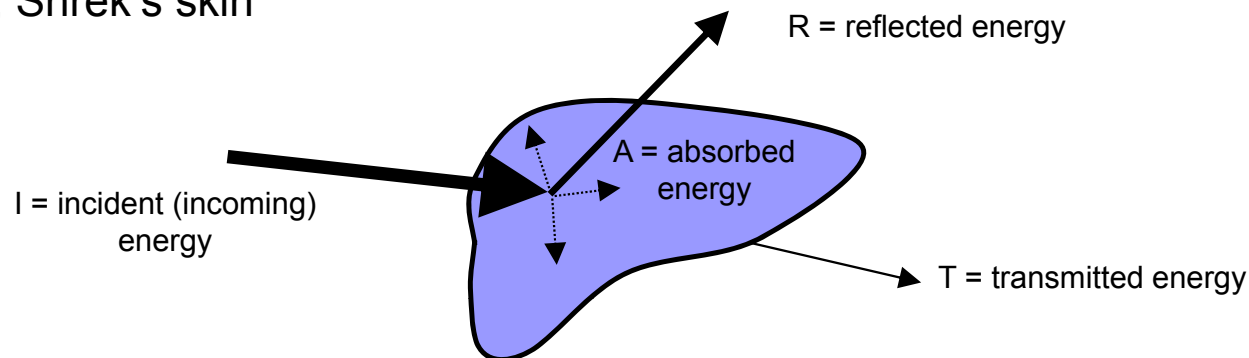


# INTERACTION OF LIGHT WITH MATERIALS

# Interaction of Light with Materials

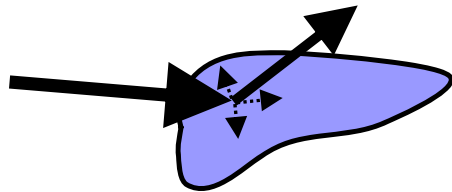
Light  $\Rightarrow$  surface of some “body”: 3 possible results

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

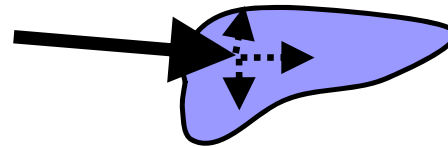


# Interaction of Light with Materials

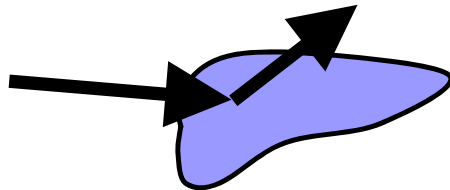
- Incident (incoming) light energy  
= absorbed energy + transmitted energy + reflected energy  
= retained + passed through + bounced off
- Chemical properties of the body determine the % of each.



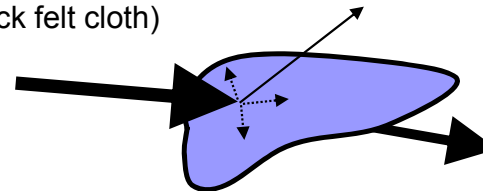
opaque coloured surface:  $A > 0$ ,  $T = 0$ ,  $R > 0$



opaque black surface:  $A = 1$ ,  $T = 0$ ,  $R = 0$   
(black felt cloth)



perfect mirror surface:  $A = 0$ ,  $T = 0$ ,  $R = 1$

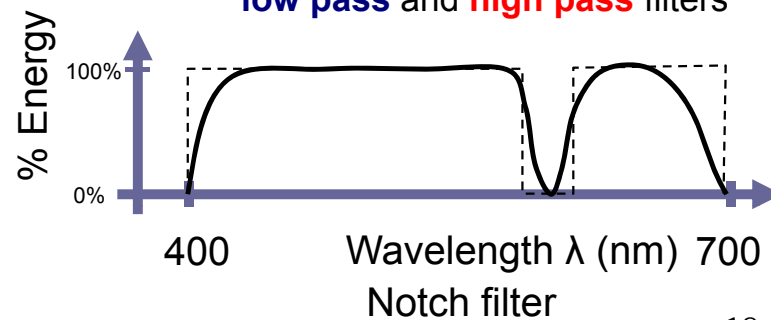
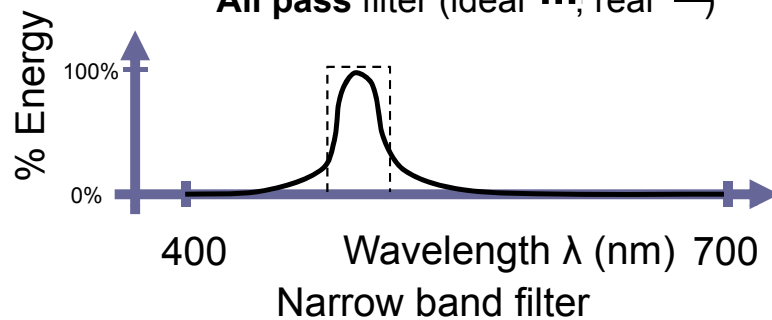
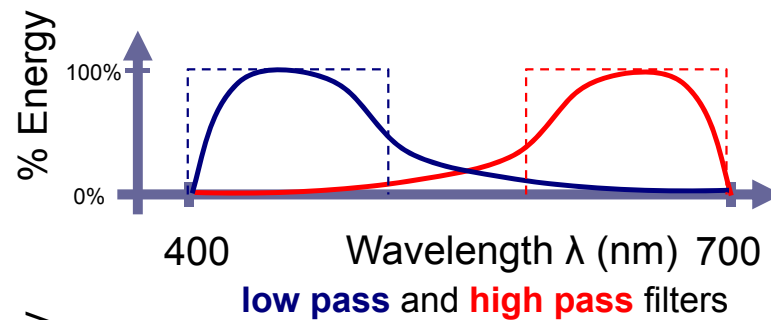
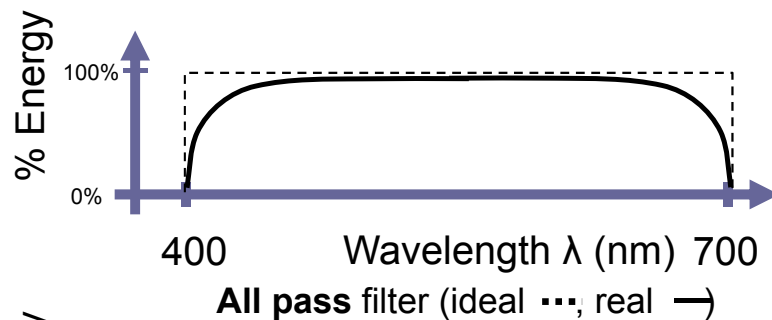


transparent surface:  $A$ ,  $R$  small,  $T \approx 1$   
(clear glass)

- Computer graphics: **reflected** (and refracted), **transmitted light**

# Spectral Response Function (SRF)

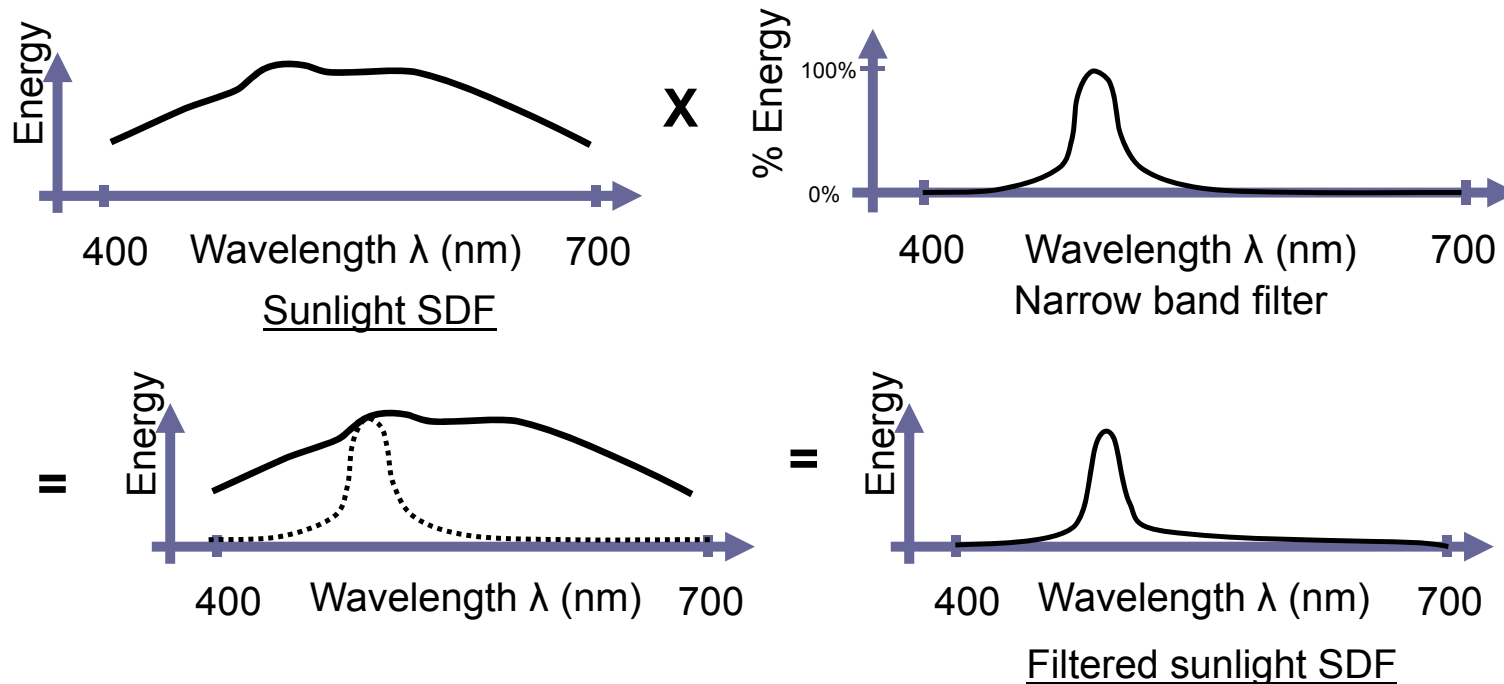
- Molecular structure of a body determines which wavelengths of light and what amount are absorbed, transmitted, or reflected
- Can be measured with a **spectral response function (SRF)** or filter function



# 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



# SDF x SRF = Result SDF

## Why is this relevant for computer graphics?

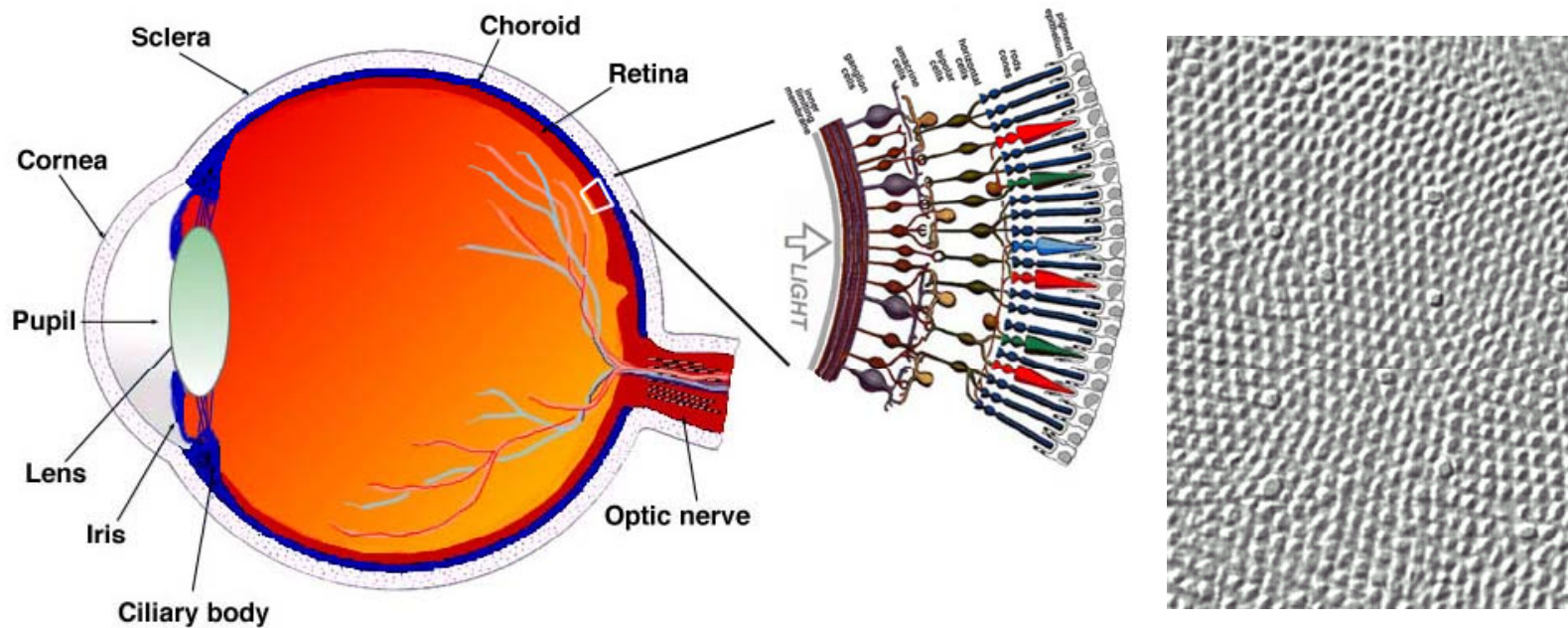
1. All light sources can be defined by their SDF
  - Natural light source: sun, fire
  - Artificial light source: light bulb, laser, LED, computer display
2. All light absorbers, transmitters, or reflectors can be defined by their SRF
  - Sensing devices: **absorbed light SRF**
    - Camera (digital photocell, film), human eye (retina)
    - Definition of “color” =  
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

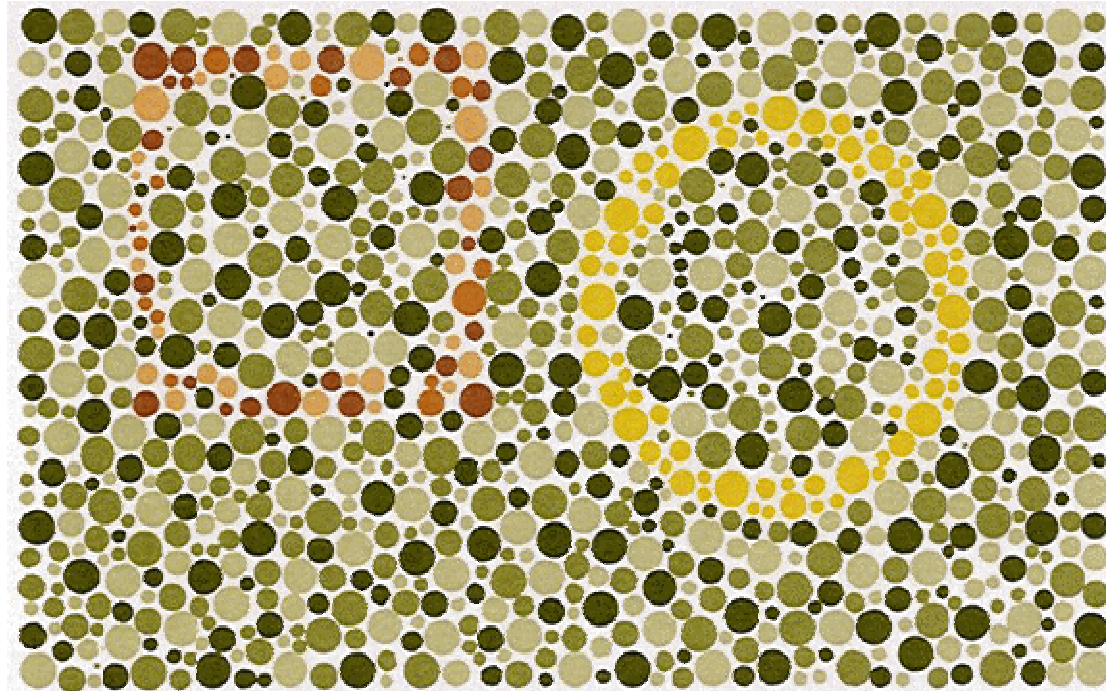
- Four types of receptors (sensors): R/G/B cones + rods, each has unique SRF



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

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

# Colour “Blindness”



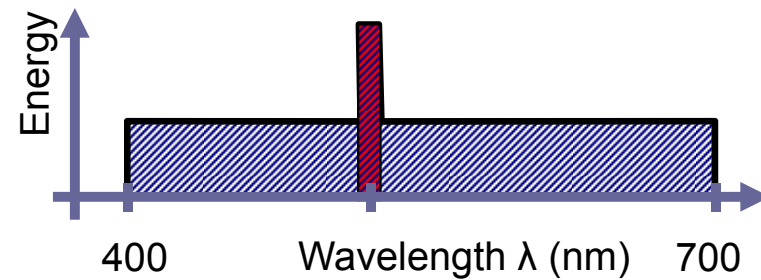
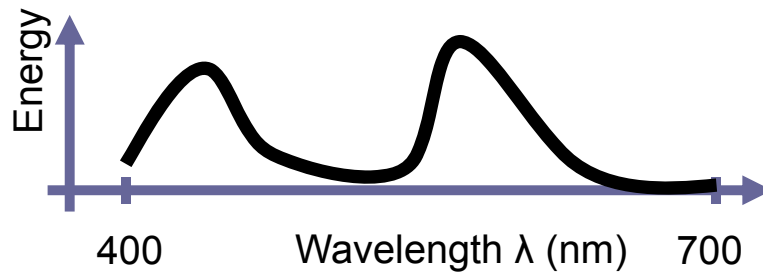
<http://members.aol.com/protanope/card2.html>

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:

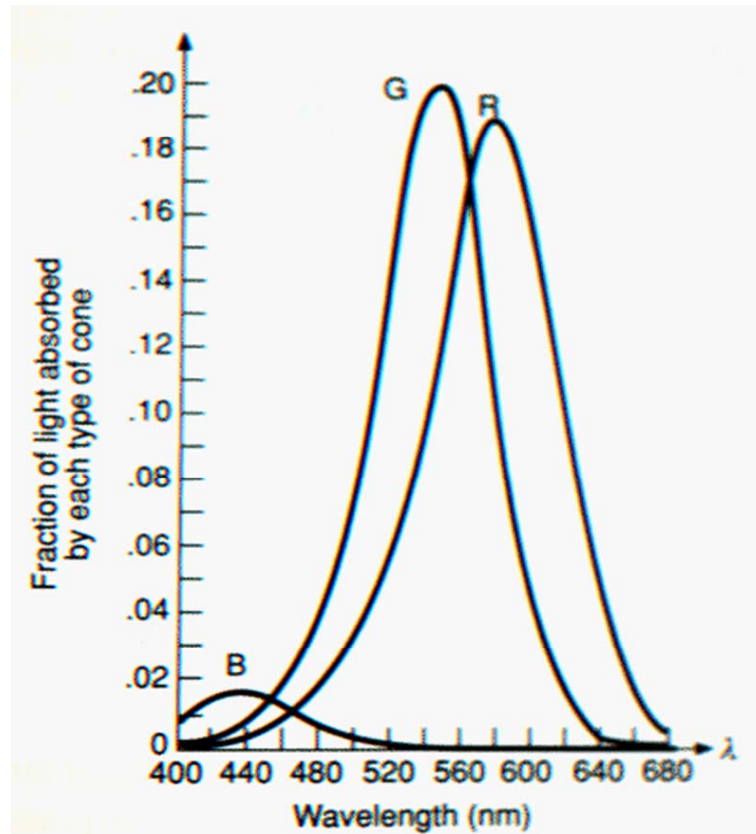
<http://www.kcl.ac.uk/teares/gktvc/vc/lt/colourblindness/cblind.htm>

# 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

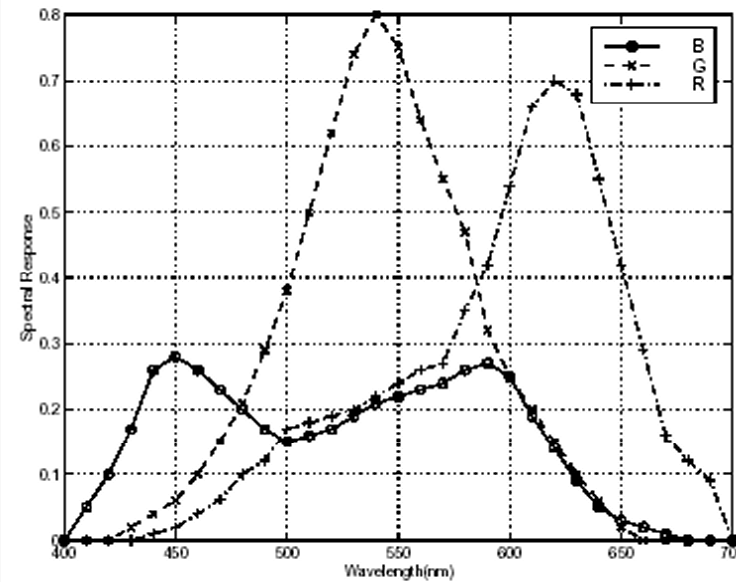


# SRFs for the Eye and a Camera



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

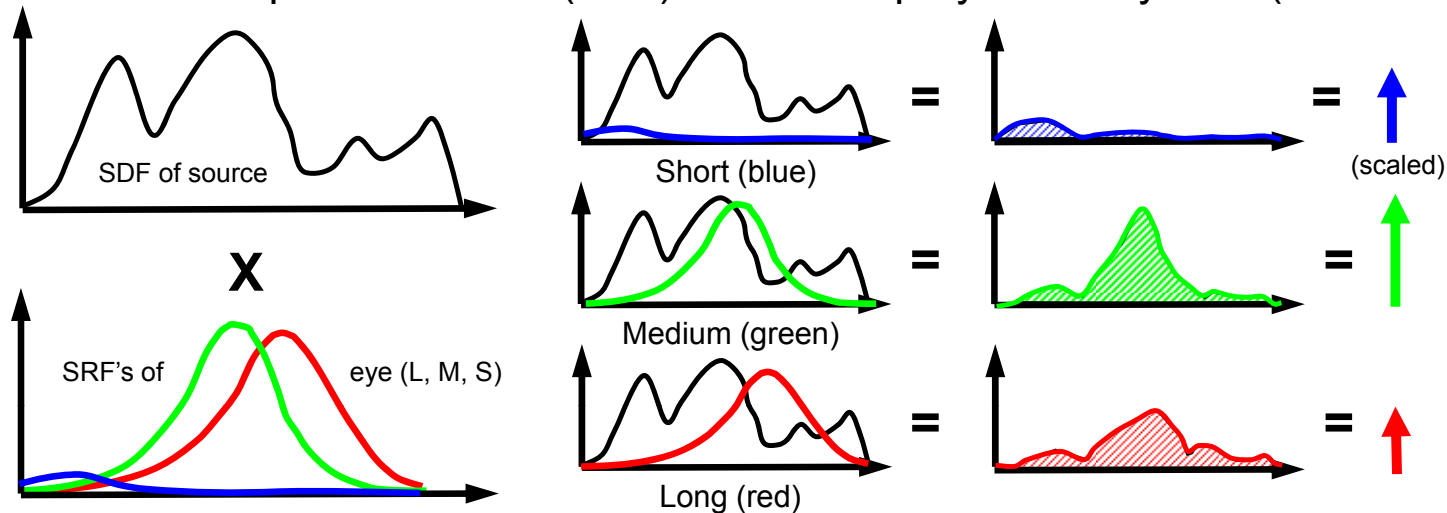
RGB spectral responses for a Kodak digital camera



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

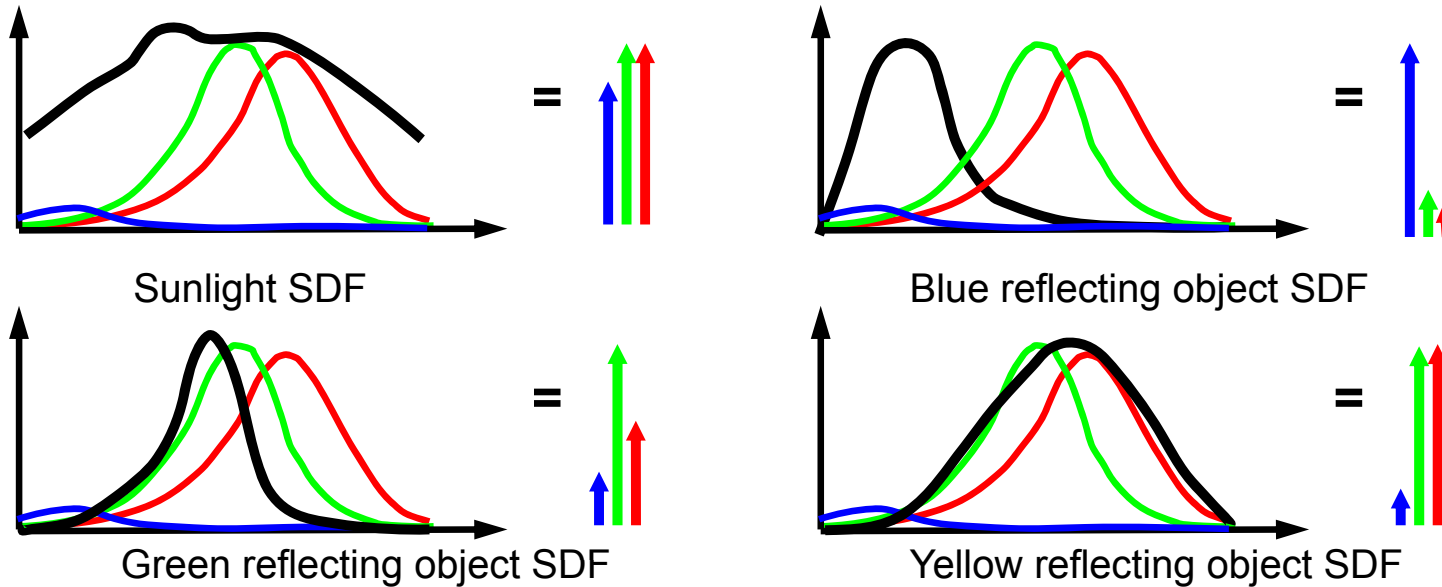
# Seeing Red, Green and Blue

- 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

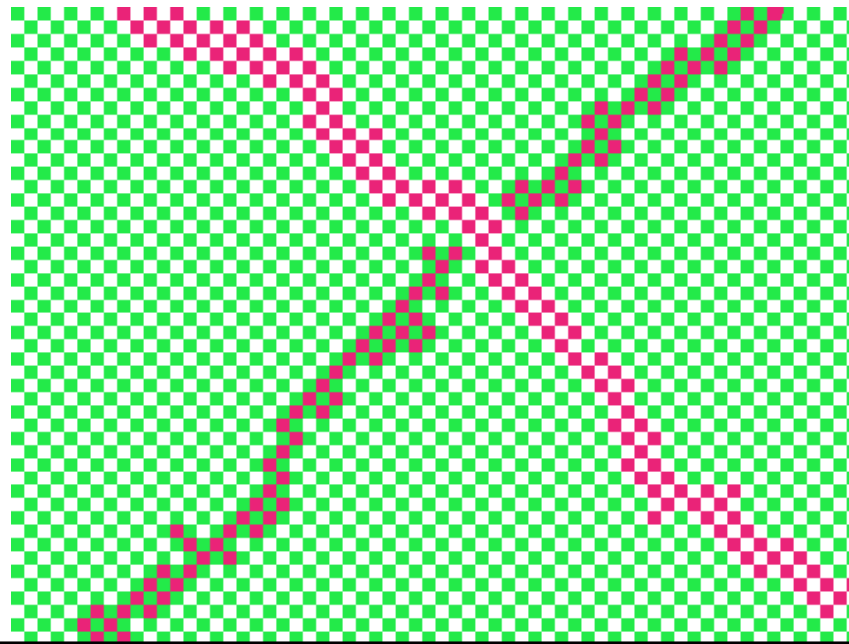
1. **Spectral Density Function (SDF)**: describes the wave composition of light with power for each wave length segment
2. **Spectral Response Function (SRF)**: can be used to specify how much % of each wave length are absorbed or reflected or transmitted
3. Light with different SDFs can have the same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



How many  
different colors?