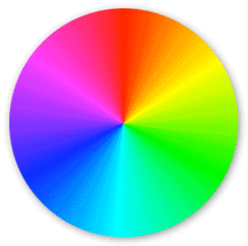
Natural Light

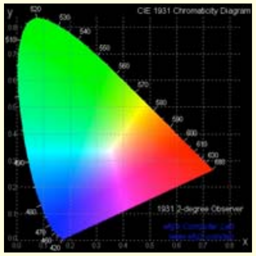
The Physiology of Color

The Natural Appearance of Things

Linear spectrum vs. color *wheel*

- The spectrum spanning blue to red wavelengths has been thus far portrayed on a linear scale
- Nature also prefers this scheme
  - prisms, rainbows, wavelengths, extension to IR, UV,…
- But we can draw a color wheel—what's up w/ that?





Color wheel physiology

- Color wheel is purely a physiological phenomenon
  - receptors in our eyes are *cyclic* in nature
  - red/green receptor and blue/yellow receptor
  - best experienced via afterimages (demo)
- Red/green receptor fires more for green, less for red
  - Hering proposed "opponent" color scheme, in which, for instance, red light *inhibits* the red/green receptor, while green light *stimulates* receptor.
  - Nicely accounts for afterimage phenomenon, but some maintain that color perception is trichromatic, with separate red, green, and blue receptors

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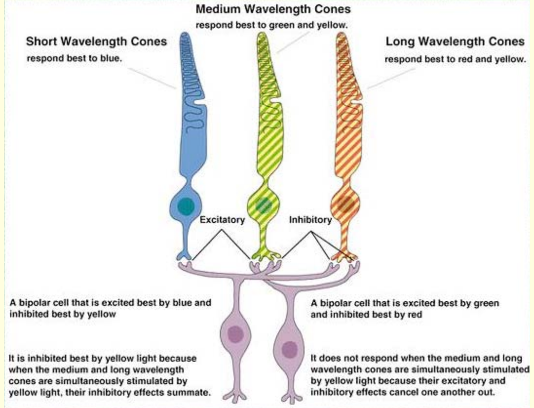
Opponent Color Receptor Theory

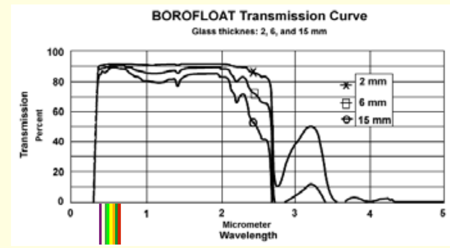


Why do things look the way they do?

- Why are metals shiny?
  - Recall that electromagnetic waves are generated from accelerating charges (i.e., electrons)
  - Electrons are free to roam in conductors (metals)
  - An EM wave incident on metal readily vibrates electrons on the surface, which subsequently generates EM radiation of exactly the same frequency (wavelength)
  - This indiscriminate vibration leads to near perfect reflection, and exact cancellation of the EM field in the interior of the metal—only surface electrons participate

What about glass?

- Why is glass clear?
  - Glass is a good insulator → electrons stay home
  - Electrons are not easily vibrated, until energy increases to UV
  - Also absorbs infrared: greenhouses retain heat (IR)



What about white stuff?

- Why is ice clear, but snow white?
  - Ice in bulk is much like glass; light passes right through
  - Tiny facets in snow reflect and refract light, presenting your eye with bewildering array of light from all directions: takes on appearance of *ambient* light
  - Salt is the same: crystal is clear, grains look white
  - Take sandpaper to Plexiglass, or scratch clear ice with skate to see the criticality of surface conditions
  - Frosted glass another good example of surface scattering

And More Questions…

- Why are raindrops on the sidewalk dark?
  - Water mediates surface roughness by filling in all the nooks and crannies
  - See into sidewalk better, without bewildering scatter
  - Same as rubbing oil on scratched Plexiglass, waxing car, applying lotion to scaly skin
- Okay, if insulators are naturally clear/translucent, then why aren't all insulators clear (paper, plastic, wood, rocks, etc.)
  - Hmm. Tough one. Muddy water isn't clear, which is related. Colloidal suspensions of junk get in the way, absorbing light
  - Surface texture also important (try wetting paper—it becomes semi-translucent)
  - Dyes and pigments selectively absorb, and are embedded in material

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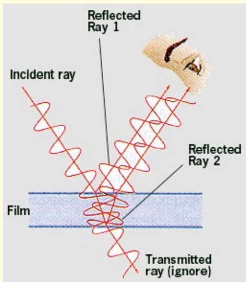
Why are soap bubbles & oil slicks colorful?



- A *thin film* reflects light from both the top *and* bottom surfaces
- Imagine the film is comparable in thickness to the wavelength of light
  - perhaps a few wavelengths thick
- The two reflected waves may add *constructively* or *destructively*
- But this is very wavelength-dependent
  - if red combines constructively, that doesn't mean blue will too
- Also very angle-dependent
  - color appears to change with viewing angle

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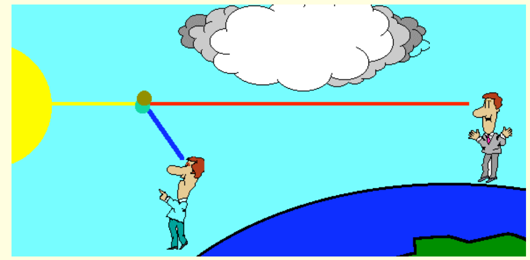
Why is the sky blue?

- Blue light more readily "scattered" by air molecules
  - called Rayleigh Scattering; *strong* function of wavelength
  - blue light in sky has been diverted from some other path
  - with some blue light missing, sun looks yellow/orange



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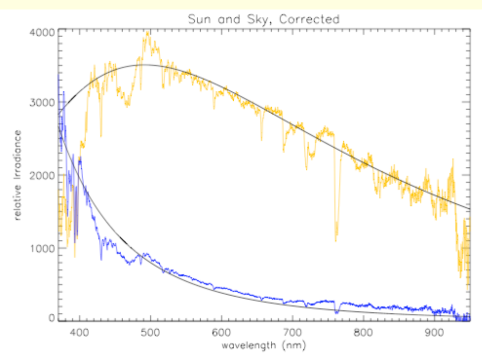
The spectrum of the blue sky



The sky (blue curve) has a spectrum that gets steeper and steeper towards the blue/violet end of the visible spectrum.

Shown on top of the blue curve is a model that goes according to theory: $1/\lambda^4$

The orange curve is the spectrum of a white piece of paper in the sun

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Is the night sky blue too?

- You bet! Just too dim to perceive
  - time exposure at night under moonlight shows this

You can find blue from scattering in other circumstances as well: water, glaciers, astrophysical reflection nebulae…

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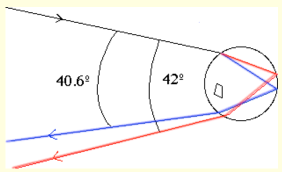
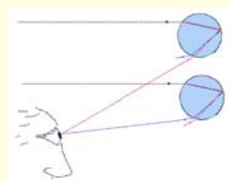
Rainbows, Halos, Sun-dogs, and More…

- Rainbows come from the interaction of sunlight with round water droplets
  - preferred single-reflection path with ~42° deflection angle
  - see http://mysite.verizon.net/vzeoacw1/rainbow.html
    - drag incoming ray, and you get a stationary behavior at 42°
  - rainbow arc always centered on *anti-solar* point
  - different colors refract at slightly different angles
    - owes to differences in *refractive index* for different colors

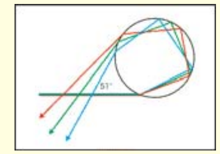


single bounce; red & blue paths different


red appears higher in sky than blue

Rainbows come in pairs…


Beautiful double rainbow in Zion National Park. The primary is brighter, and the color sequence is reversed from that seen in fainter secondary.

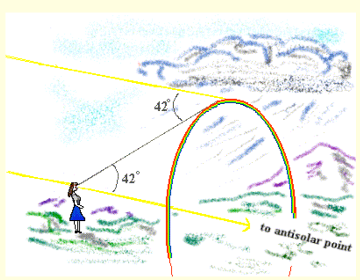

Secondary rainbow has two reflections. Red now appears *lower* than blue in the sky.

Area between rainbows often seen to be darker than elsewhere.

Note: rainbow can exist in foreground.

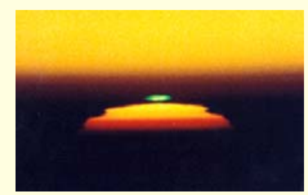
Questions

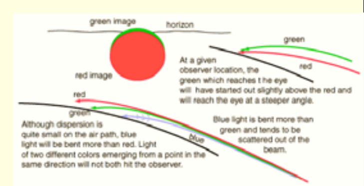
- Which general direction will a rainbow be found in the evening?
- Why don't you see rainbows during the middle of the day?



The Green Flash

- The atmosphere acts like a mild prism: the refractive index varies slightly with wavelength
- Exaggerated low on horizon
- Different colors bent different amounts by atmosphere
  - the whole sun is bent 0.6° at the horizon
  - it has actually set before its refracted image sets!
- Red image sets first, followed by green
  - the blue has long been scattered away

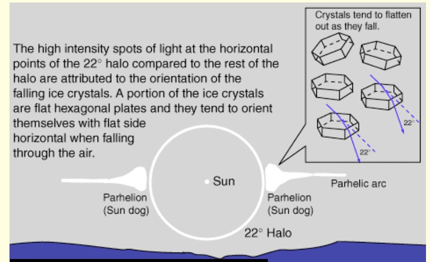




The halo, and sun-dogs

- 22° halo around sun due to hexagonal ice crystals
  - often more noticeable around moon at night (less glare)
- Sun-dogs (parhelia) join halo, level with sun
  - from *horizontally* situated ice crystals
    - akin to leaves falling in stable horizontal orientation
  - colored due to refractive dispersion through ice crystal

Sun-dog geometry

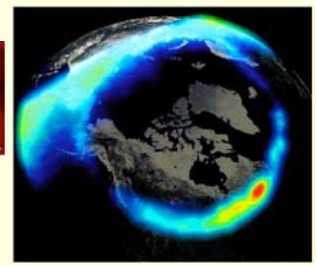


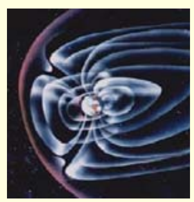
Antarctic skies: lots of ice…

Glorys and Heiligenschein (shadow-hiding)

- A circular rainbow about the anti-solar direction is called a *glory*
  - Sometimes 2–3 colored rings
  - often see shadow in middle
  - water droplet phenomenon
- The anti-solar point may also get bright due to shadow-hiding
  - called heiligenschein
  - often see from airplane over textured terrain
  - no, the person in the photo is *not* an angel

Aurora Borealis





- Aurorae happen when charged particles from the sun (protons and electrons) leap out from a solar flare, and impinge on the earth.
- For the most part, earth's magnetic field deflects these particles, but some find cracks near the poles
- When the energetic (fast-moving) charged particles hit the upper atmosphere, they knock atoms silly, and we see the glow as deposed electrons rejoin their parents

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References and Assignments

- References
  - Lynch & Livingston's *Color and Light in Nature*
  - Minnaert's *Light and Color in the Outdoors*
  - Eugene Hecht's *Optics* (advanced text, but chapter 1 history is very thorough, section 4.4 is good, *great* pictures throughout!)
- Assignments
  - HW8 TBA
  - Q/O # 5 due Next Friday 6/9
  - Final Exam Wed 6/14 3-6 PM WLH 2005
  - will have study guide and review session as for midterm

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