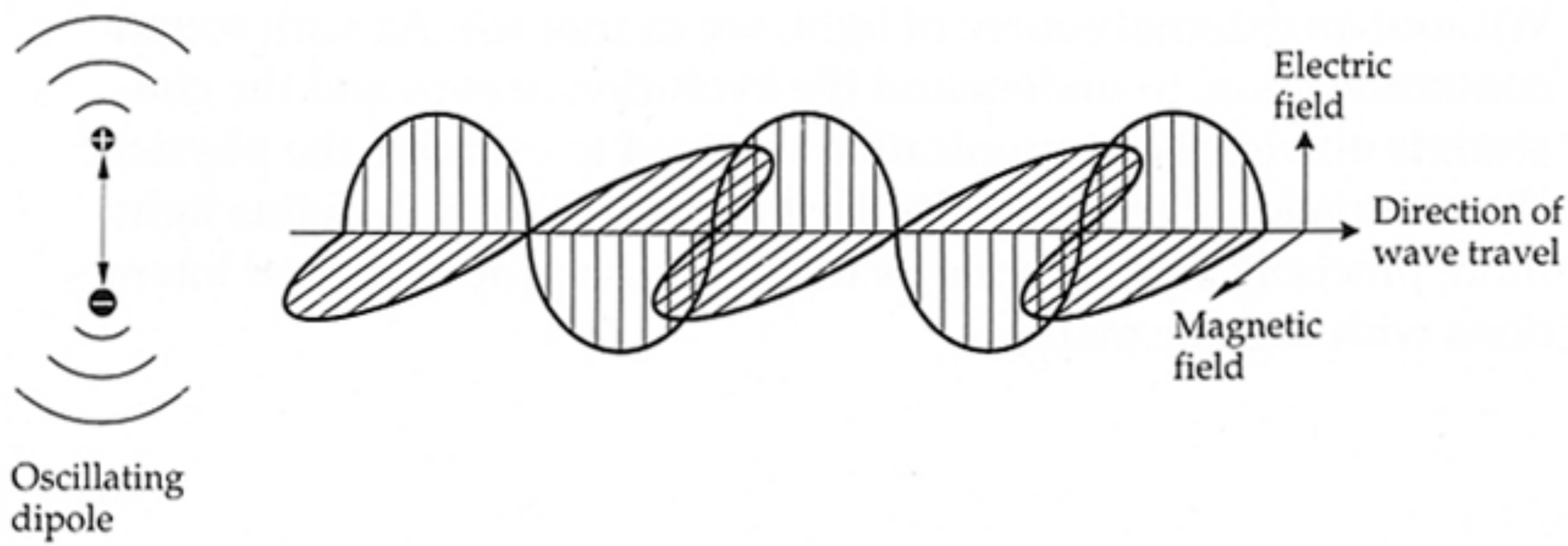
Properties of Light

- Waves, particles and EM spectrum
- Interaction with matter
- Absorption
- Reflection, refraction and scattering
- Polarization and diffraction
- Reading foci: pp 175-185, 191-199 not responsible for boxes 7.1 and 7.2

EM Wave

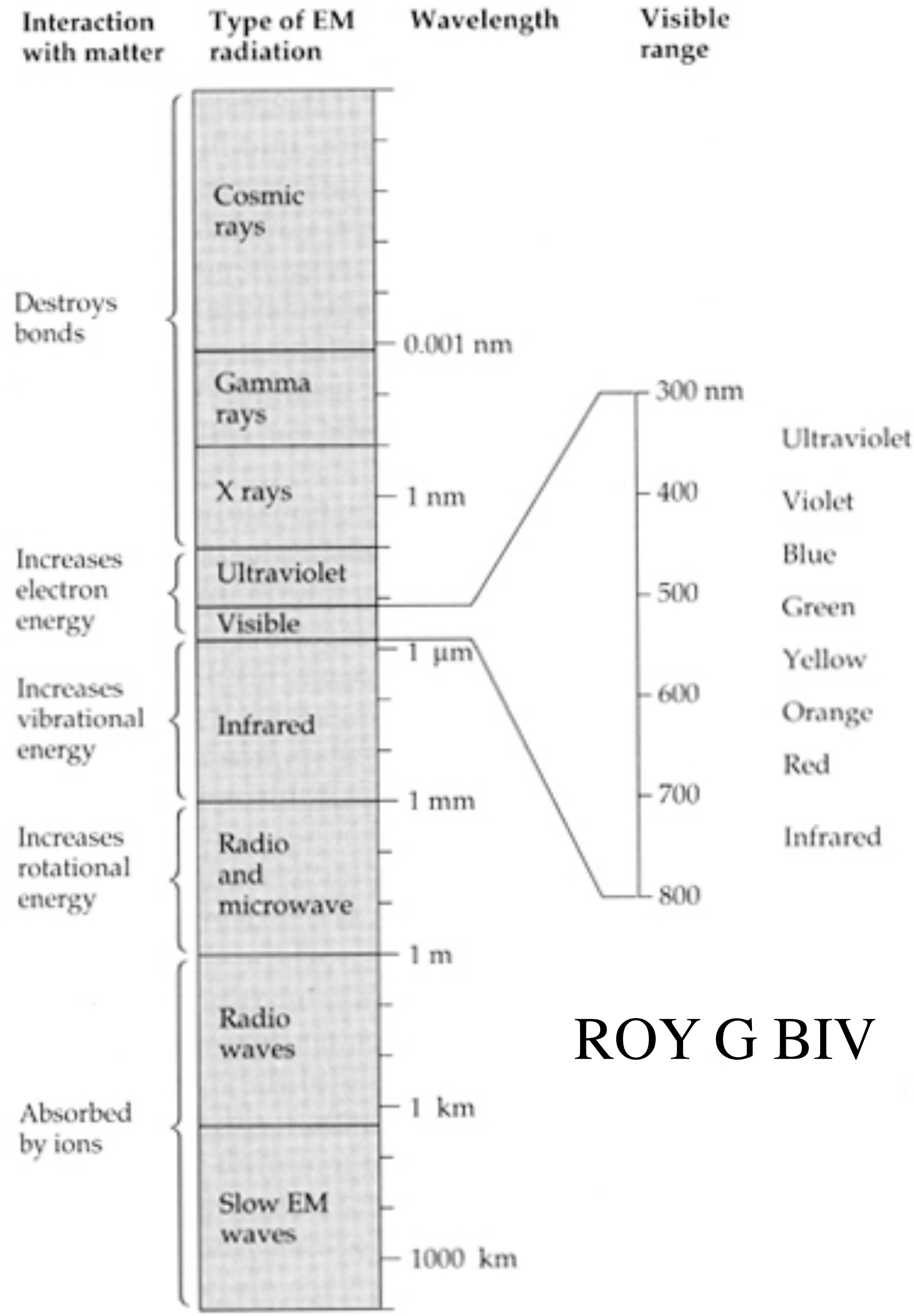


- EM waves are generated by vibrating electrons
- Composed of two perpendicular oscillating fields
- Can be characterized by its frequency, which is inversely related to wavelength ($f = c / \lambda$)
- Shares with sound the properties of spreading loss, attenuation, reflection, refraction, and diffraction, but can travel in vacuum

High frequency EM acts like a particle, can split atoms

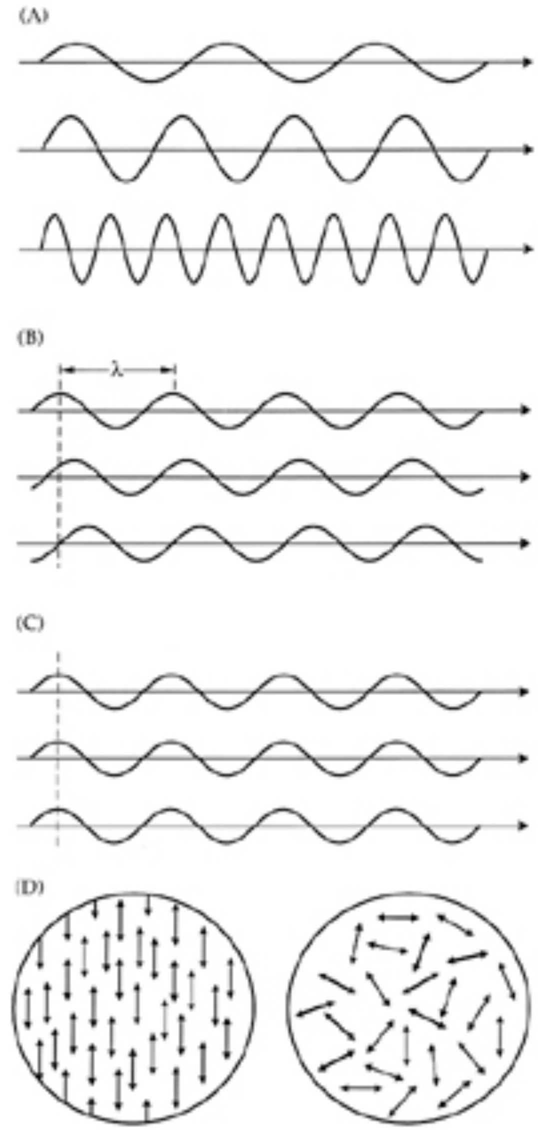
Electromagnetic spectra

Low frequency EM acts like a wave



ROY G BIV

Light waves



Complex light (sunlight)

Single wave = monochromatic light

Coherent light (in phase) = laser

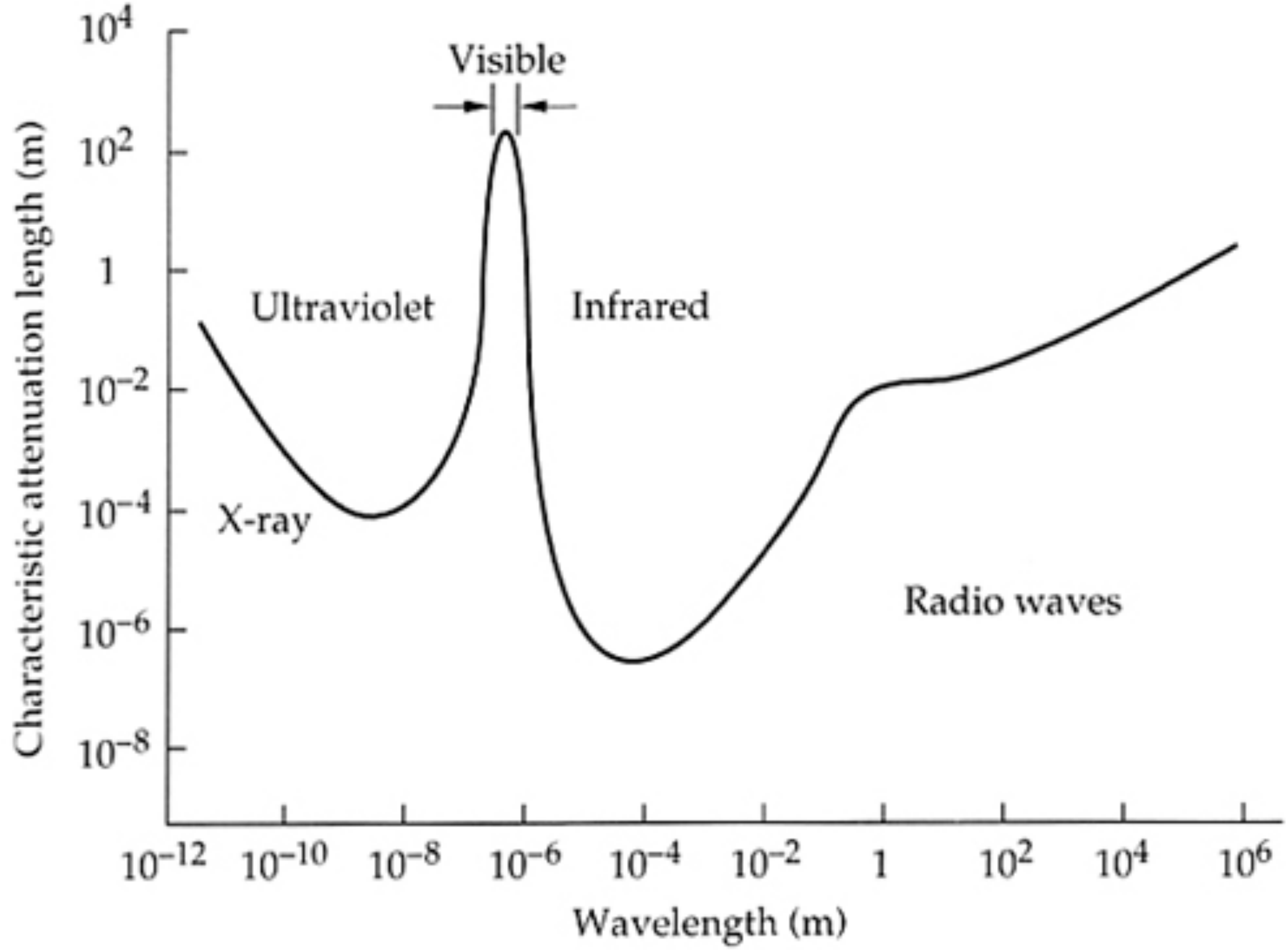
Polarized light

http://micro.magnet.fsu.edu/primer/java/scienceopticsu/polarizedlight/filters/index.html

Interaction with matter

- All molecules have resonant frequencies at which they trap particular EM wavelengths
- Long wavelength EM (radiowaves) is not absorbed by biological materials
- Short microwaves increase atomic motion, especially water, and create heat
- Infrared radiation also increases atomic motion of some molecules and is perceived as heat
  - Pit vipers and vampire bats have IR sensors
- Shortest x-rays and cosmic rays destroy molecules
- Energy in visible light is absorbed without damage to cells
  - Special molecules (visual pigments) make use of changes in electron orbital states

Absorption by water depends on wavelength



Absorption vs propagation of light

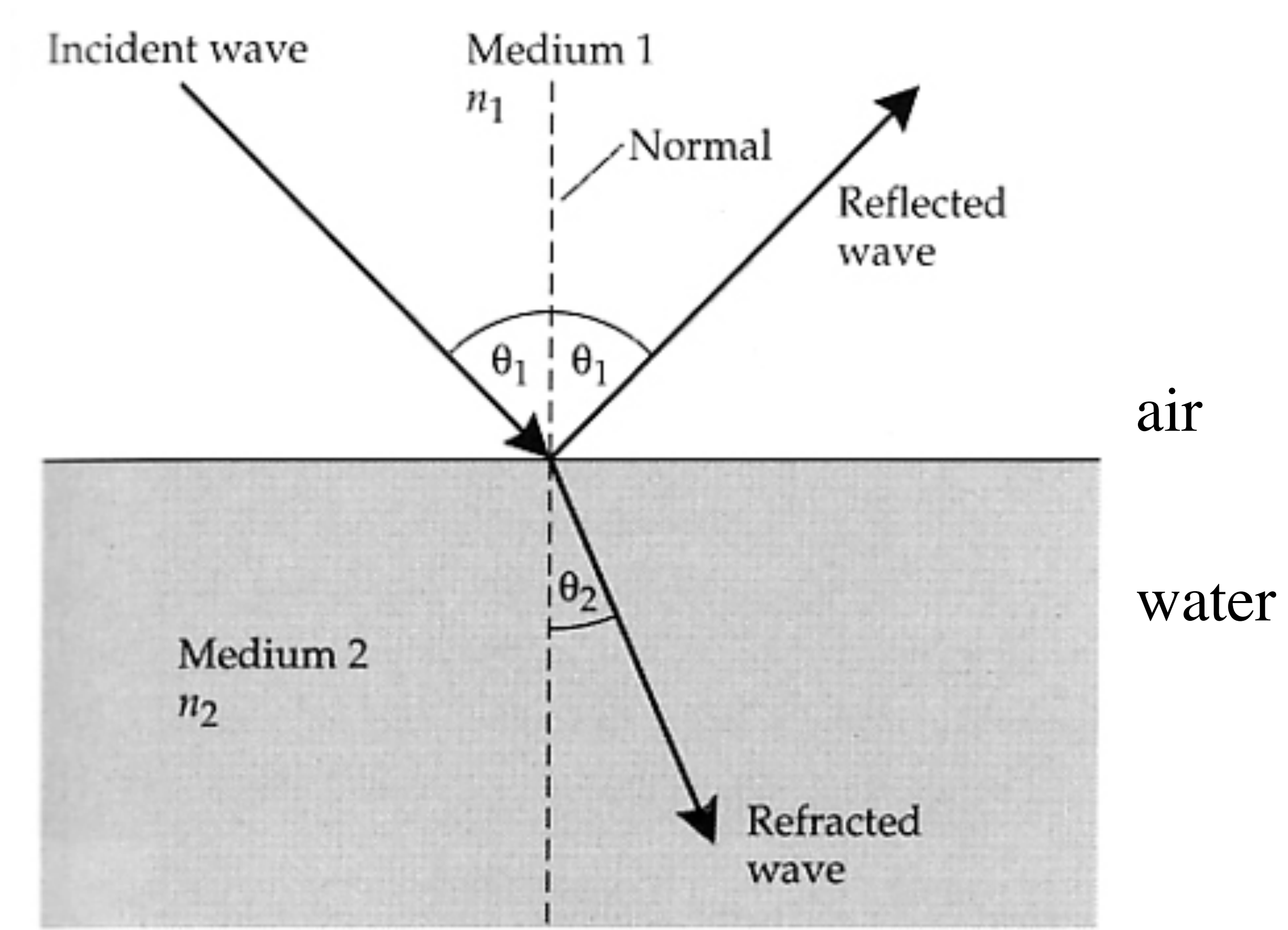
- If light wave frequency = molecules resonant frequency
  - Light is absorbed (propagation is stopped)
  - Medium is opaque
- If light wave frequency ≠ molecules resonant frequency
  - Light is reradiated and propagated forward through medium
  - Medium is transparent
- In a solid or liquid, propagation is in straight line
- In a gas, propagation is less organized and scatter increases

Speed of light depends on media

Medium	Speed (m/s)	Refractive index
Vacuum	3×10^8	
Air	2.99×10^8	1.00028
Water	2.25×10^8	1.33
Glass	1.99×10^8	1.5
Diamond	1.25×10^8	2.4

Speed of light is slower in water than in air (opposite to sound)

Light reflects and refracts



When 2nd medium has slower speed, light refracts towards normal

Refraction

Figure 3

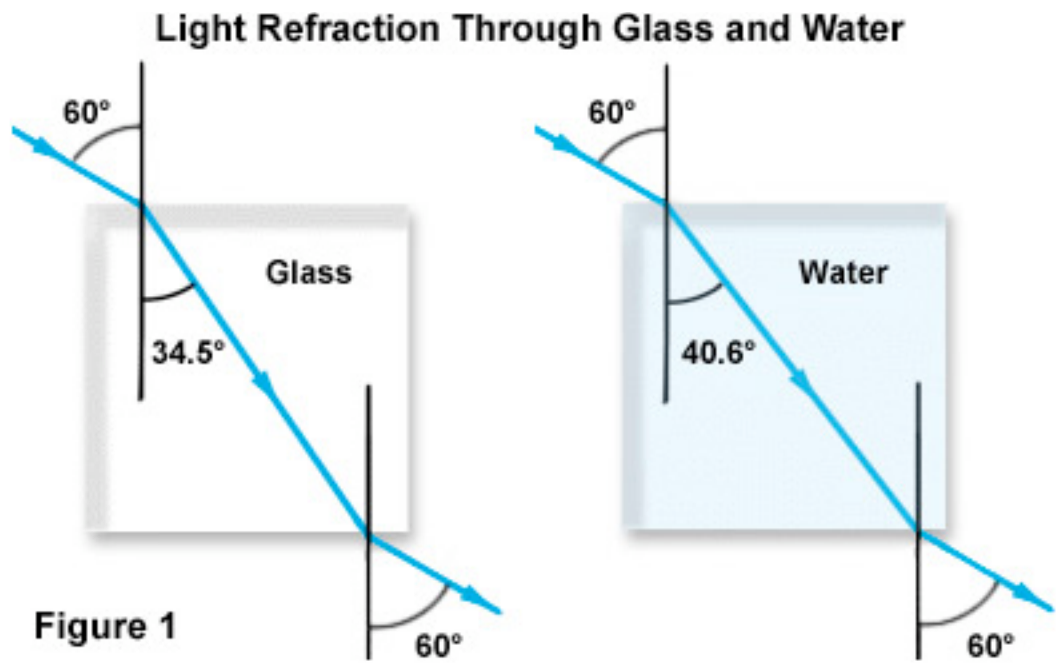
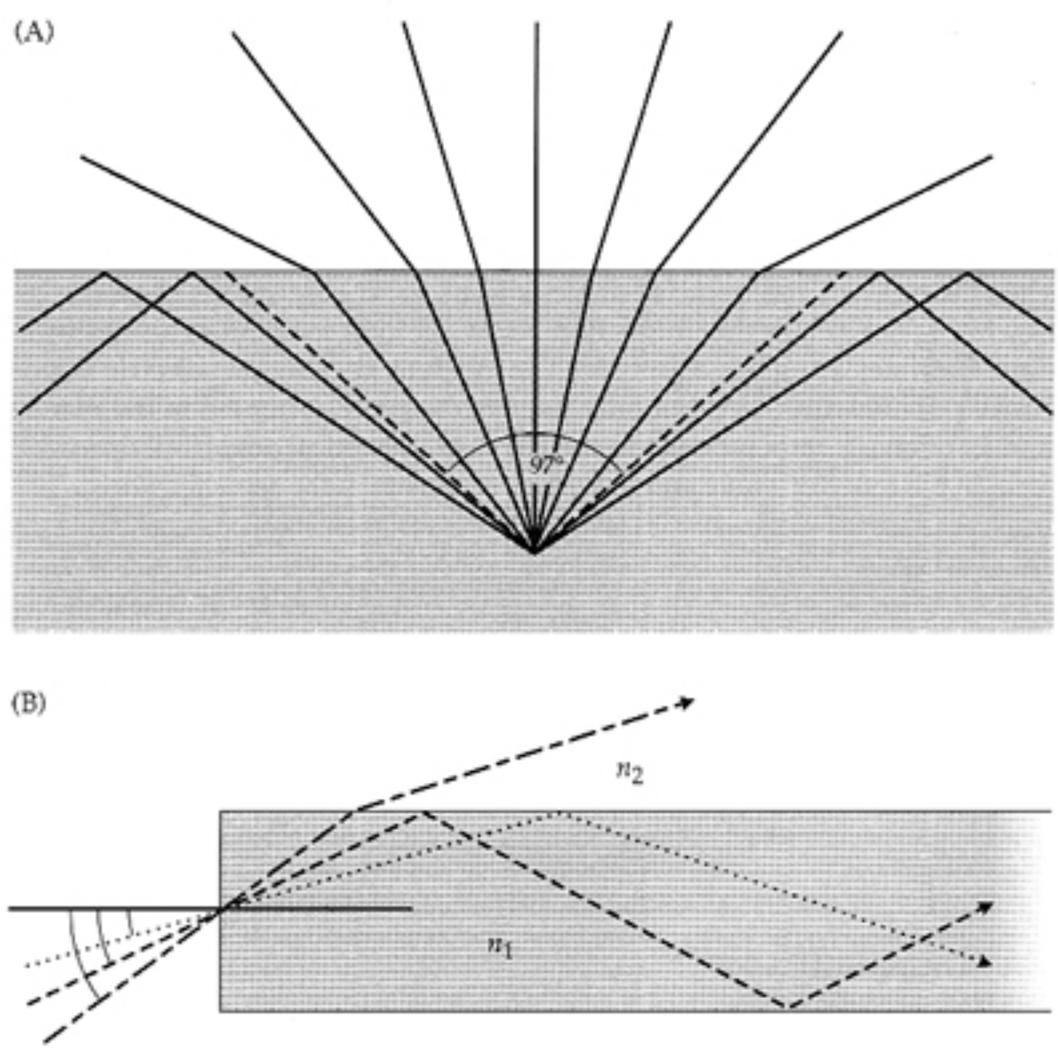


Figure 1

http://micro.magnet.fsu.edu/optics/lightandcolor/refraction.html

Large angle causes internal reflections

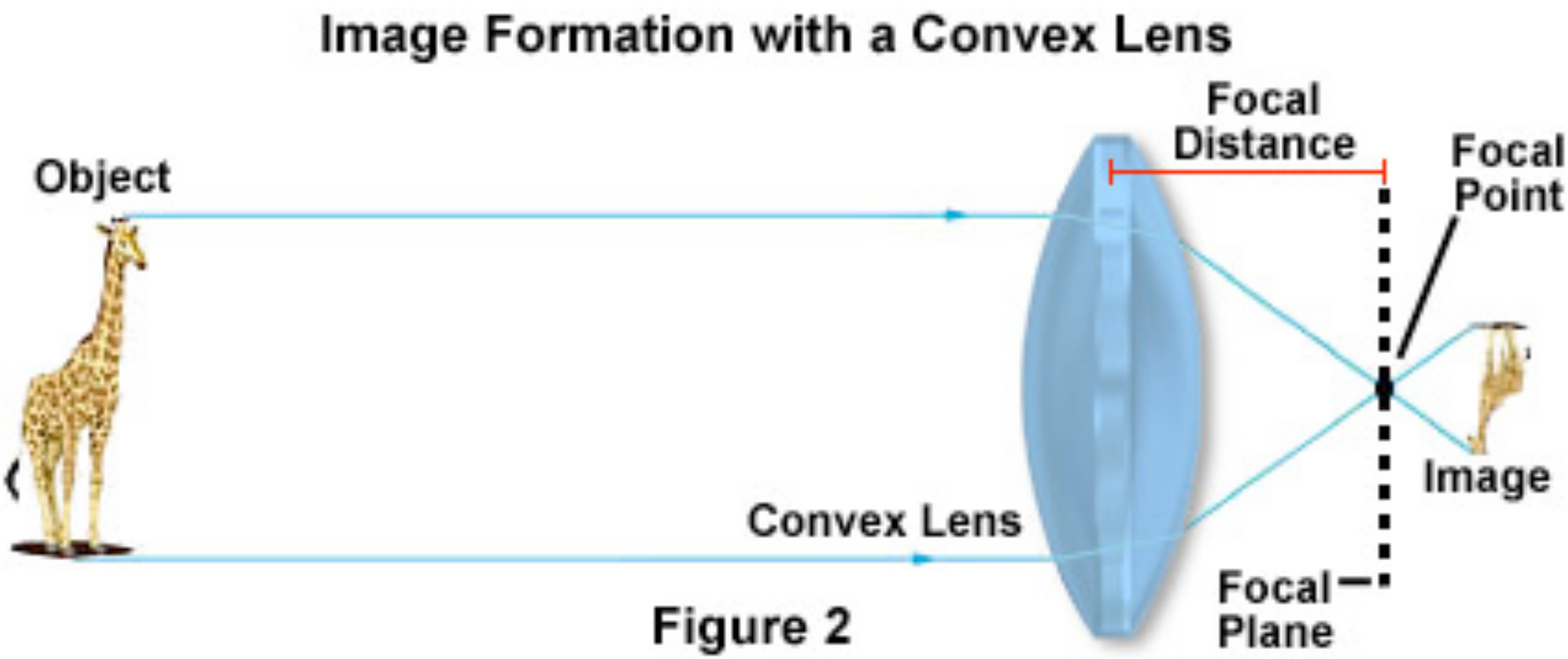


air

water

Receptor
cell

Lenses focus light



http://micro.magnet.fsu.edu/optics/lightandcolor/lenses.html

Far and near sightedness

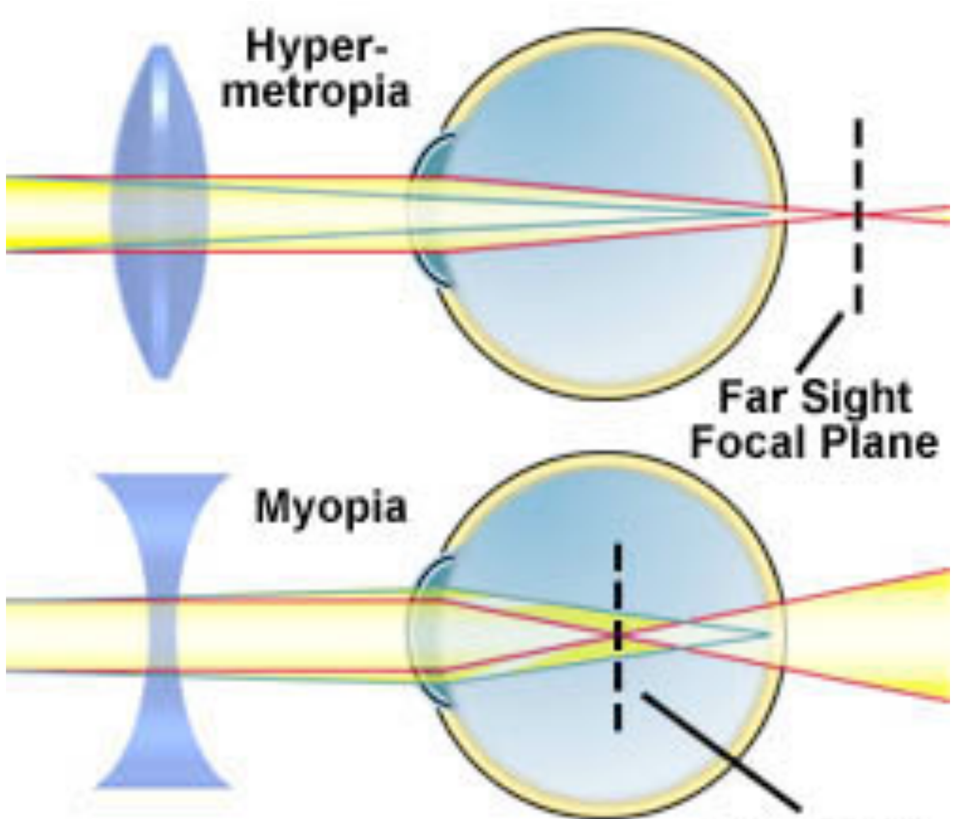
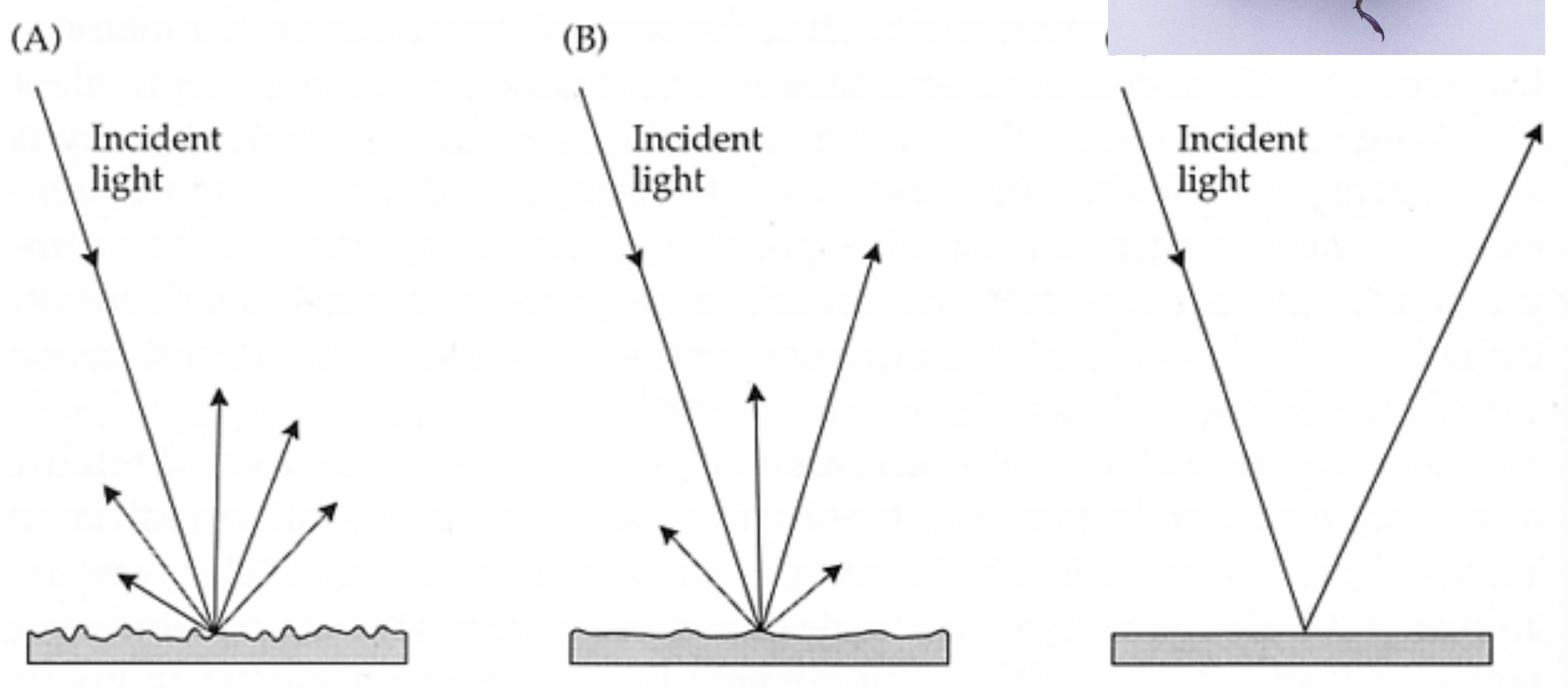


Figure 3

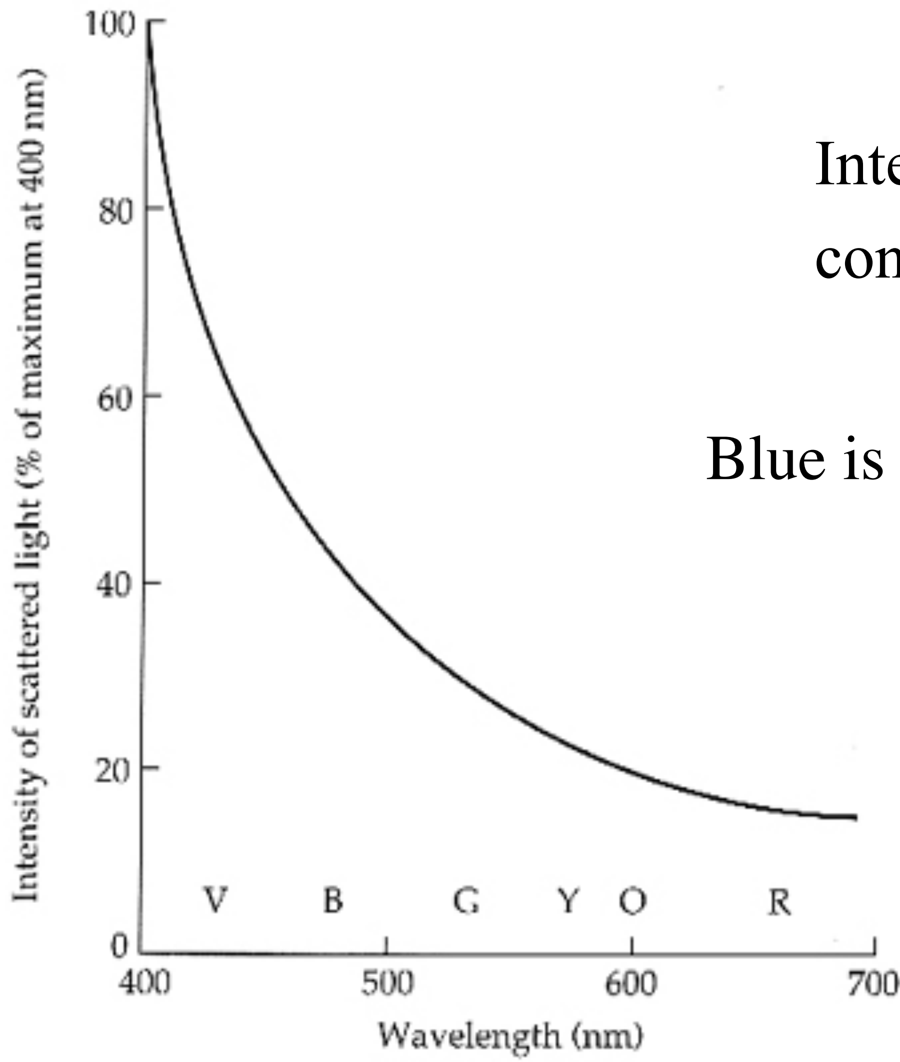
Reflectance



Diffuse (dull, matte)

Specular (shiny)

Scatter depends on wavelength

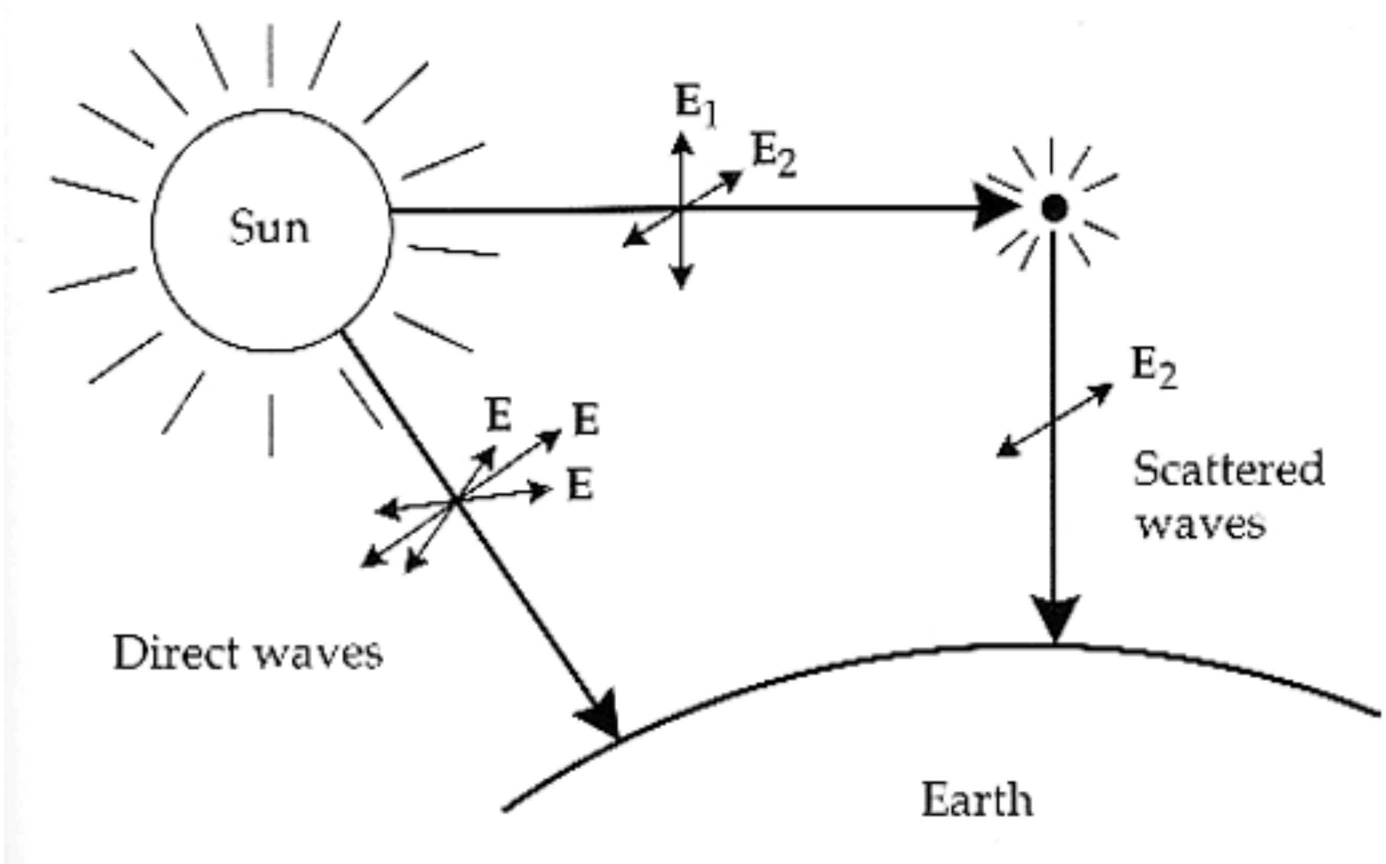


Intensity of scattering = constant / wavelength^4

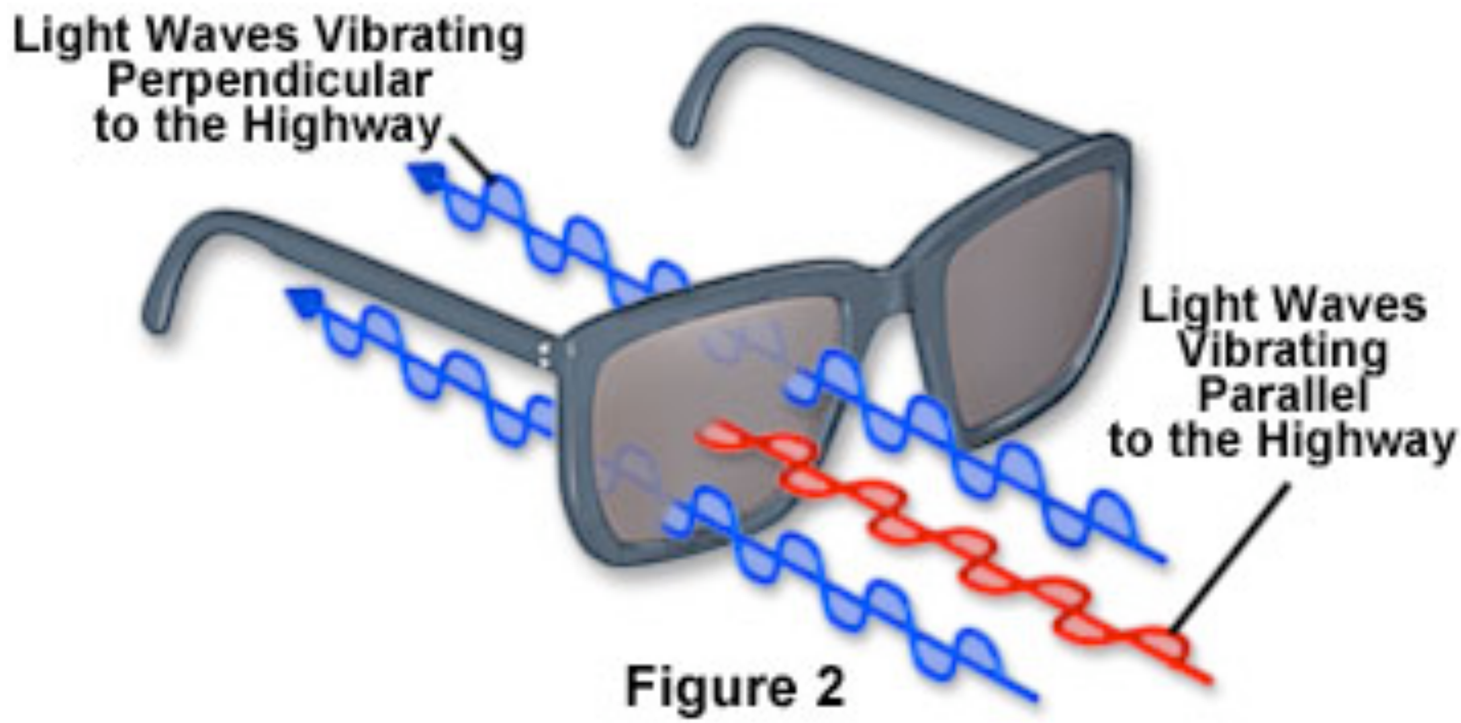
Blue is scattered more than yellow

Figure 7.10 Rayleigh scattering of light. Violet (V) and blue (B) wavelengths are scattered more than the longer wavelengths of green (G), yellow (Y), orange (O), and red (R).

Sun is yellow, sky is blue



Polarized Light



http://micro.magnet.fsu.edu/primer/java/scienceopticsu/polarizedlight/filters/index.html

Polarized light indicates solar position

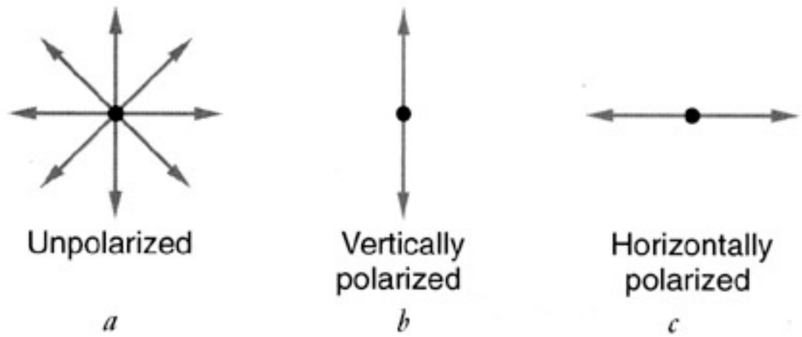
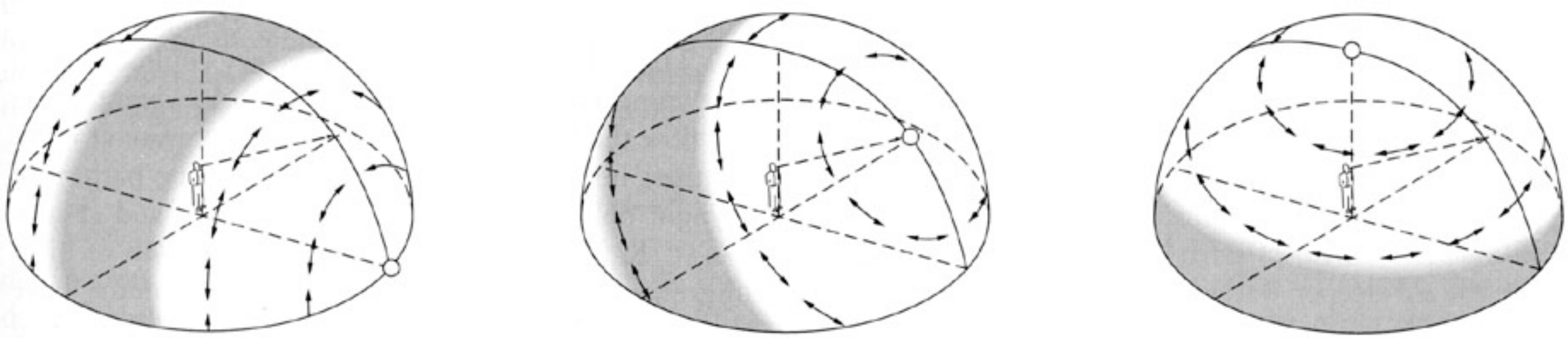


FIGURE 10.17 Unpolarized and polarized light. The arrows show the planes of vibration of a light beam that is coming straight out of the page.

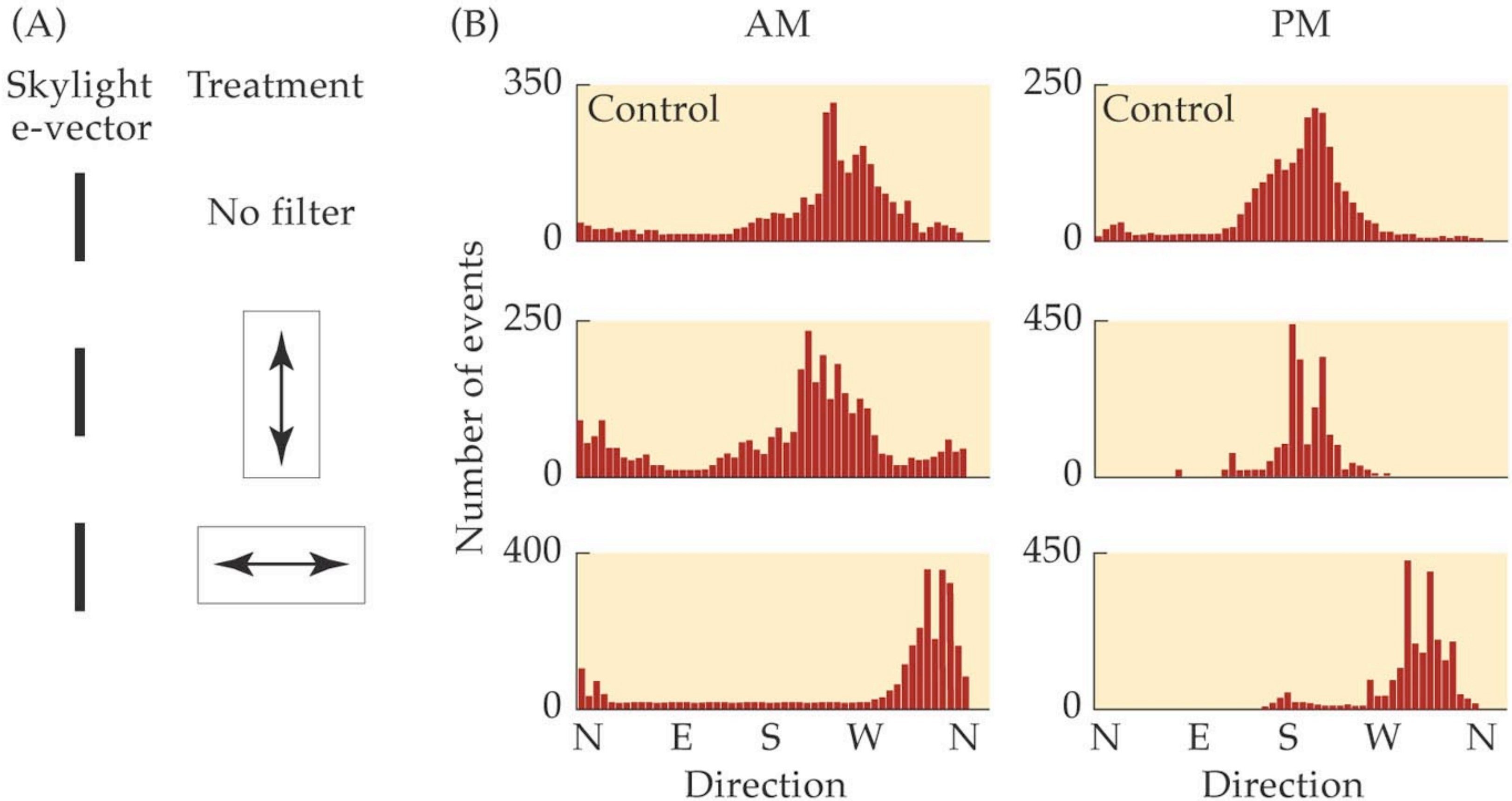


d Sun at horizon (dawn)

e Sun at 45 degree elevation (perhaps 9 am)

f Sun at zenith (noon)

Monarch butterflies can use polarized light to orient



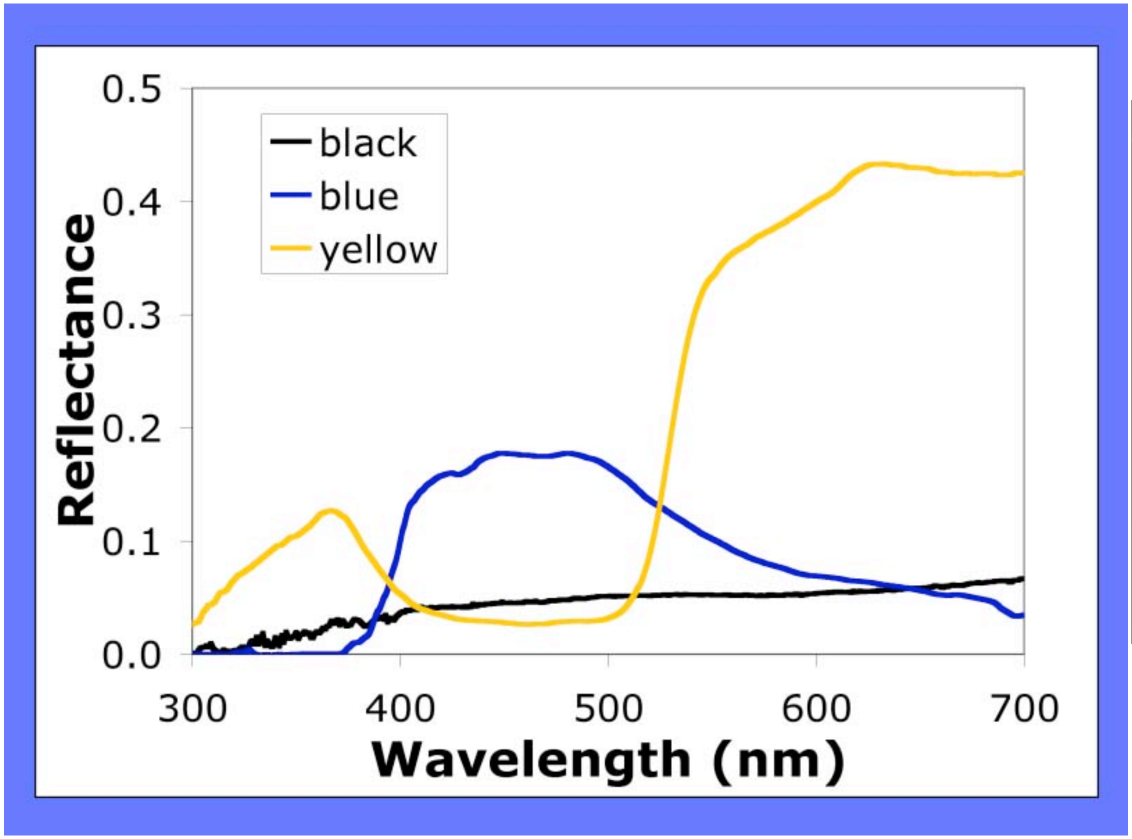
Flight direction of tethered butterflies

Measuring light intensity

- Irradiance is total amount of light incident on a surface
  - Includes scattered light
  - Measured with a 180° lens (photographic light meter)
- Radiance is light emitted from specific area
  - Measured with tube over area of interest
  - Must specify angle of measurement
- Both measurements can be made wavelength-specific by filtering out other wavelengths
  - A series of measurements creates an irradiance or radiance spectrum (in wavelengths)

Radiance spectra example

(courtesy of Karen Carleton)



Metriaclima zebra 'gold'

Absorption depends on frequency

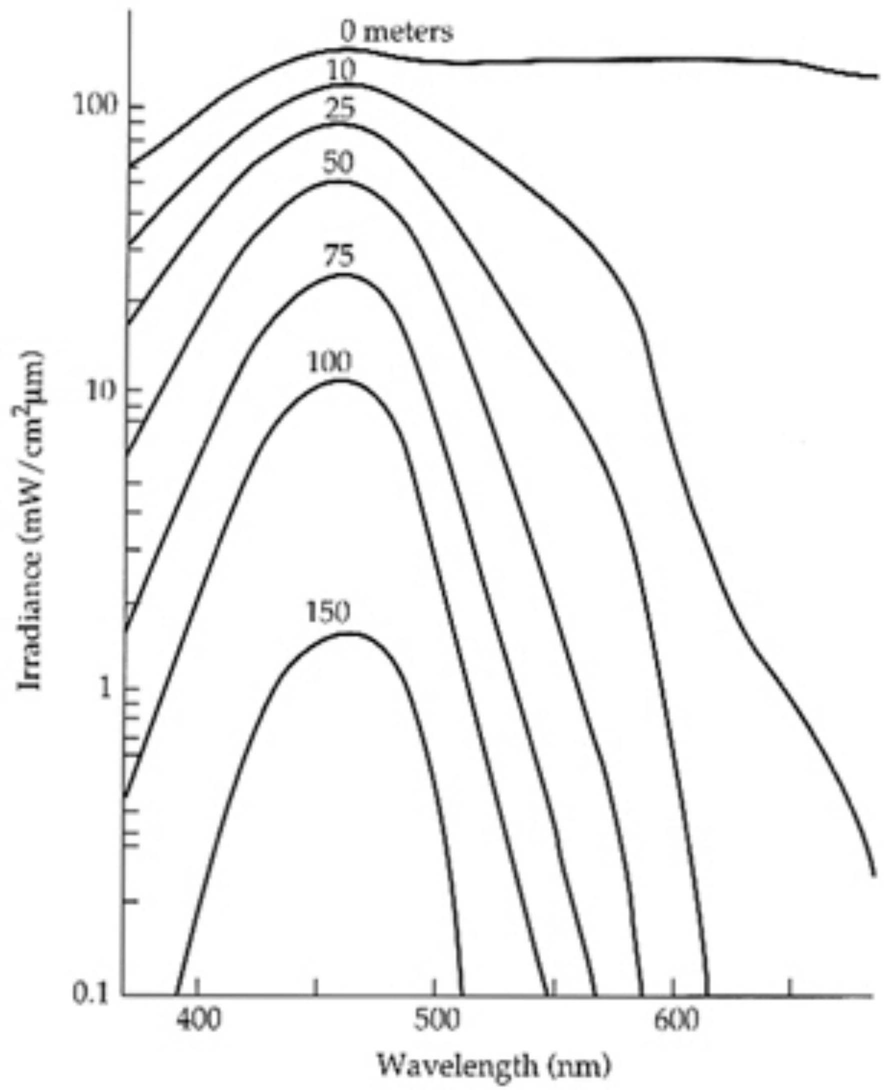


Figure 7.12 Irradiance frequency spectra in water at different depths. The intensity of longer wavelengths in the red region drops off very quickly with increasing depth because of selective absorption. Ultraviolet and violet wavelengths are also absorbed. The consequence is an increasingly monochromatic blue medium at greater depths. (From Waterman 1981, based on Lundgren and Højerslev 1971.)

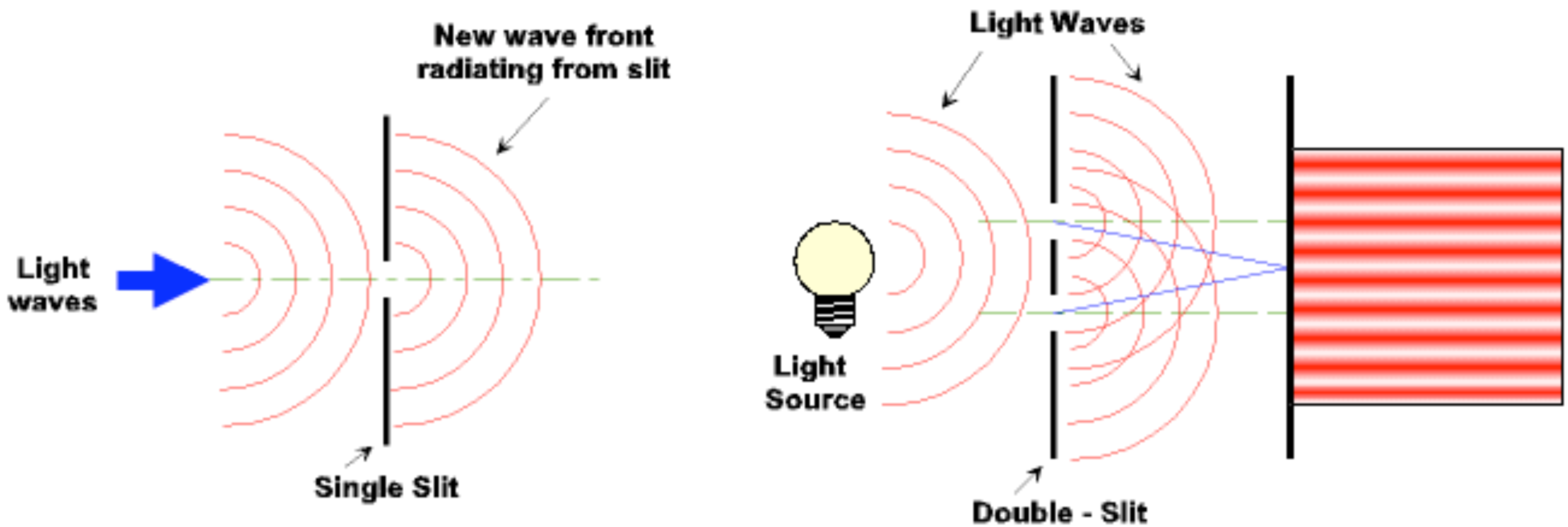
Water absorbs red faster than blue

Refraction depends on frequency

http://www.allfloyd.com/images/covers/darkside.jpg

Refraction causes rainbows

Light Diffraction



Propagation of light through a slit demonstrates wave properties. Cancellation and addition of diffracted waves results in striped pattern in contrast to what would be expected by particles.

http://www.physics.uoguelph.ca/applets/Intro_physics/kisalev/java/slitdiffr/index.html

Why light works for visual communication

- Can be absorbed without damage to cells
- Most abundant wavelengths
- Reflects off solid objects
  - Higher and lower frequencies pass through or bend around
- Straight-line transmission without scatter
  - Permits formation of spatial maps
- Refraction at the boundary of two media
  - Permits focusing and image formation by an eye behind a lens
- Frequency dependent effects influence colors