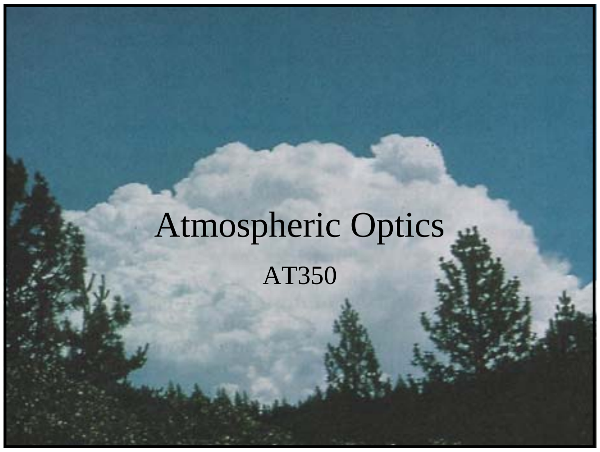
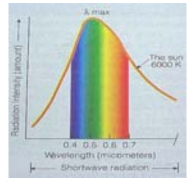


Atmospheric Optics

AT350

Colors and Brightness



- ~50% of the sun's energy enters our atmosphere as visible light
- Visible light in the atmosphere can be
  - Reflected, refracted, scattered
  - Absorbed
  - Transmitted
- What we see, and what it looks like, depends on these phenomena
  - Light waves stimulate nerve endings in the retina
  - Rods respond to all visible wavelengths and "measure" brightness
  - Cones respond to specific wavelengths between 0.4 and 0.7 µm
    - Without cones, our vision would be B&W
    - Defective or missing cones cause color blindness

Object Color

- White corresponds to similar amounts of all visible wavelengths striking eye cones
- Objects that emit visible light can appear colored if some wavelengths are emitted more strongly
  - Spectrum depends on object T
- Cooler objects can appear colored if they absorb selected visible wavelengths
  - e.g., a red object is absorbing all wavelengths except those in the red range

Light Scattering

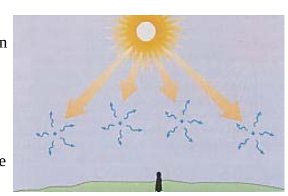
- Light can be thought of as a set of electromagnetic waves.
- Light is scattered when these waves interact with other objects. The nature of the scattering depends on the object properties, especially the size of the object
- Three scattering types
  - Rayleigh scattering: the object is much smaller than the wavelength of light (~0.4-0.7 µm)
    - scattering proportional to $1/\lambda^4$
    - Shorter (violet, blue) wavelengths scattered more efficiently

Light Scattering (cont'd)

- Mie Scattering: The object is similar in size to the wavelength of light
  - Most efficient scattering (light scattered from a cross-section up to several times the object cross-section)
  - Calculation of light scattering amount complex (Maxwell's Equations)
  - Many air pollution particles are in this size range
- Geometric Scattering: The object is much larger than the light wavelength
  - Cloud drops are geometric scatterers
  - Visible wavelengths scattered with similar efficiency
  - Object scatters a cross-section of incoming light equal to twice its own cross-section
    - Consider the Extinction Paradox

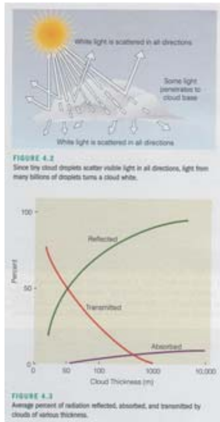
Why is the day sky blue?

- Sunlight is scattered by air molecules
- Air molecules are much smaller than the light's λ
- Rayleigh scattering (proportional to $1/\lambda^4$) occurs
- Shorter wavelengths (green, blue, violet) scattered more efficiently
- Unless we are looking directly at the sun, we are viewing light scattered by the atmosphere, so the color we see is dominated by short visible wavelengths
  - blue dominates over violet because our eyes are more sensitive to blue light



What makes clouds white/grey/black?

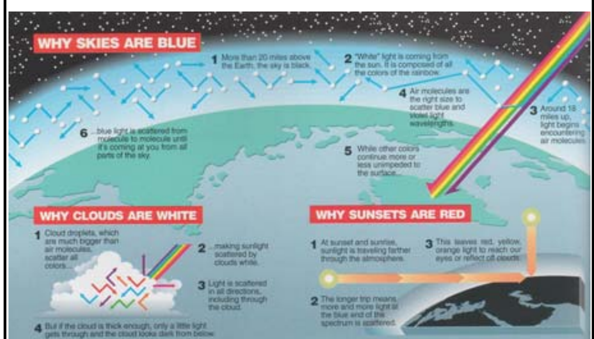
- Cloud drops are ~ 5-50 µm
  - Geometric scatterers
  - All visible λ's scattered with similar efficiency
- When clouds are viewed from above they appear bright white
  - Backscattered sunlight
- When viewed from below, clouds can appear white, grey or black
  - Transmitted and forward-scattered light make thin clouds appear white
  - Thicker clouds
    - Scatter and absorb more light
    - Can appear dark/black
    - Large drops are better absorbers



Why are sunsets red?

- The sun appears fairly white when it's high in the sky
- Near the horizon, sunlight must penetrate a much greater atmospheric path
  - More scattering
- In a clean atmosphere, scattering by gases removes short visible λ's from the line-of-sight
  - Sun appears orange/yellow because only longer wavelengths make it through
- When particle concentrations are high, the slightly longer yellow λ's are also scattered
  - Mie scattering
  - Sun appears red/orange

Blue sky summary



Other Atmospheric Scattering Examples

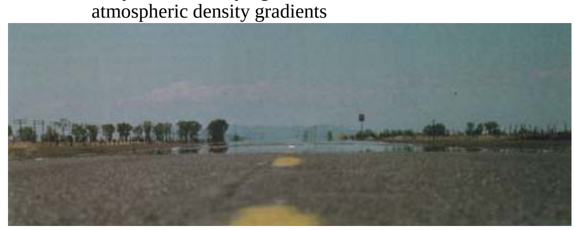
Refraction

- The speed of light changes as the light enters regions of different density
  - Speed slows/rises as density rises/falls
  - If entrance to the new range is made at an angle, the light bends (refraction)
    - Toward/away from the normal for increasing/decreasing density

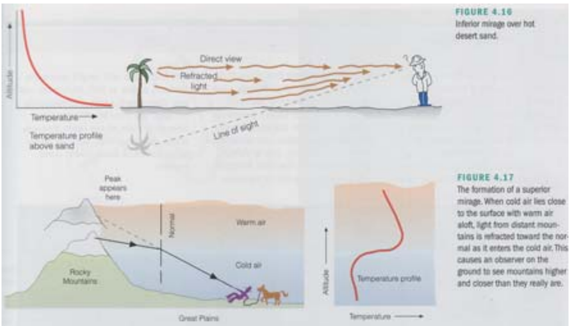
- Atmospheric refraction changes the apparent position of light sources (objects)
- How does this affect
  - Time of sunset ?
  - Twilight ?

What are mirages?

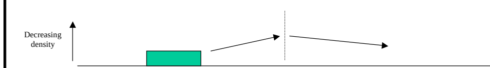
- A mirage occurs when an object appears displaced from its true position
  - Mirages are not mind tricks
  - They are caused by light refraction associated with atmospheric density gradients



Mirage schematics

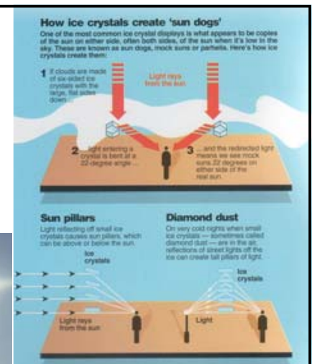


Fata Morgana

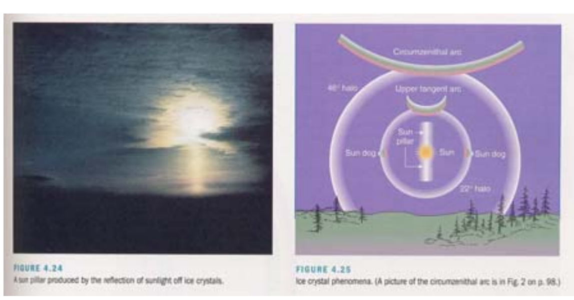


Coronas and halos

Sun dogs and pillars



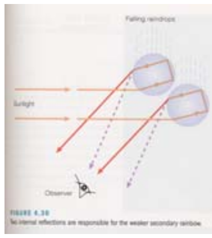
Ice crystal optics summary



Rainbows

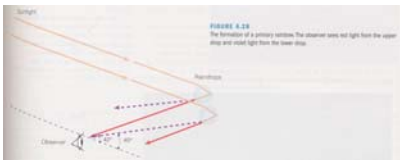
- Internal reflection of sunlight by raindrops
  - Light entering denser drop slows and bends
  - Short wavelengths refract the most
  - Most light passes through drop, but some strikes backside at ***critical angle*** (~ 42 degrees, depending on λ) and is reflected
- Light refraction experiment by Newton in 17th century provided first scientific explanation
- Occurs when sun is at our back
- Rainbow most likely when sun is close to the horizon
- Rainbow would form full circle if horizon were absent
- Different colors seen in rainbow come from drops at different heights
- Double rainbows possible when two internal reflections occur
  - Second rainbow weaker because it comes from two reflections
- Moonbows and fogbows also possible

Rainbow schematics



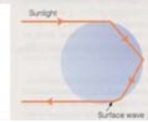
- Rainbow in morning, sailors take warning

  Rainbow at night, a sailor's delight



The glory

- Aircraft above cloud layer
- Drops < 50 μm
- Refraction, internal reflection and surface skimming
- Slightly different departure angles for different λ's produce colored rings



Questions for thought

- Why are star colors related to star temperatures while planet colors are not related to planet temperatures?
- How long does twilight last on the moon?
- What would the sky color be if air molecules scattered long λ's more efficiently?
- Why does smoke arising from a cigarette often have a blue cast yet appear white when blown from the mouth?
- Why are stars more visible with no moon out?