Light, Color, and Atmospheric Optics

GEOL 1350: Introduction To Meteorology

Overview

Scattering

Aerosol Scattering
Reflection, Refraction, Diffraction

Various Optical Phenomena
Blue Skies, Rainbows

Scattering

- During the scattering process, no energy is gained or lost, and therefore, no temperature changes occur.
- Scattering depends on the size of objects, in particular on the ratio of object's diameter vs wavelength:

1. Rayleigh scattering ($D/\lambda < 0.03$)
2. Mie scattering ($0.03 \leq D/\lambda < 32$)
3. Geometric scattering ($D/\lambda \geq 32$)

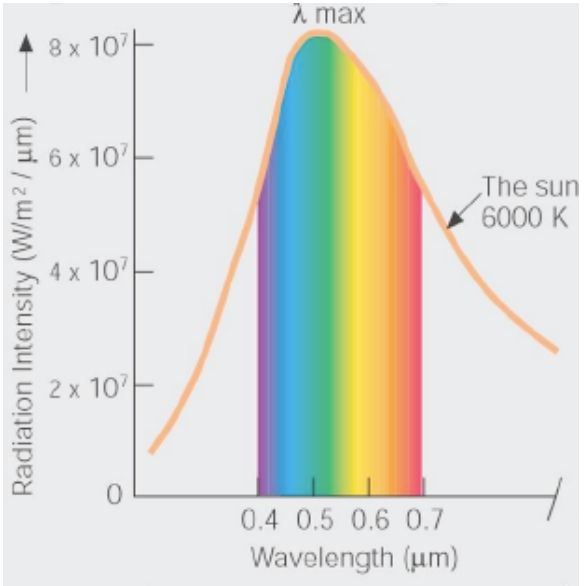
Scattering

Table 4.1 The Various Types of Scattering of Visible Light

TYPE OF PARTICLE	PARTICLE DIAMETER (MICROMETERS, μm)	TYPE OF SCATTERING	PHENOMENA
Air molecules	0.0001 to 0.001	Rayleigh	Blue sky, red sunsets
Aerosols (pollutants)	0.01 to 1.0	Mie	Brownish smog
Cloud droplets	10 to 100	Geometric	White clouds

Scattering

- **Gas scattering: redirection of radiation by a gas molecule without a net transfer of energy of the molecules**
- **Rayleigh scattering: absorption extinction coefficient σ_s depends on $1/\lambda^4$.**
- **Molecules scatter short (blue) wavelengths preferentially over long (red) wavelengths.**
- **The longer pathway of light through the atmosphere the more shorter wavelengths are scattered.**



Scattering

- As sunlight enters the atmosphere, the shorter visible wavelengths of violet, blue and green are scattered more by atmospheric gases than are the longer wavelengths of yellow, orange, and especially red.
- The scattered waves of violet, blue, and green strike the eye from all directions.
- Because our eyes are more sensitive to blue light, these waves, viewed together, produce the sensation of blue coming from all around us.

Scattering

- **Rayleigh Scattering**
- **The selective scattering of blue light by air molecules and very small particles can make distant mountains appear blue.**

The blue ridge mountains in Virginia.

Scattering

- When small particles, such as fine dust and salt, become suspended in the atmosphere, the color of the sky begins to change from blue to milky white.
- These particles are large enough to scatter all wavelengths of visible light fairly evenly in all directions.
- More particles, more scattering, and the whiter the sky becomes.
- A similar effect occurs when the sun shines through a break in a layer of clouds. Dust, tiny water droplets, or haze in the air beneath the clouds scatter sunlight, making that region of the sky appear bright with rays.

Scattering

- Near sunrise or sunset, the rays coming directly from the sun strike the atmosphere at a low angle.
- They must pass through much more atmosphere than at any other time during the day.
- By the time sunlight has penetrated this large amount of air, most of the shorter waves of visible light have been scattered away by the air molecules.
- Clean Air: Bright, yellow-orange sunsets
- When the atmosphere becomes loaded with particles, only the longest red wavelengths are able to penetrate the atmosphere, and we see a red sun.

Aerosol Scattering

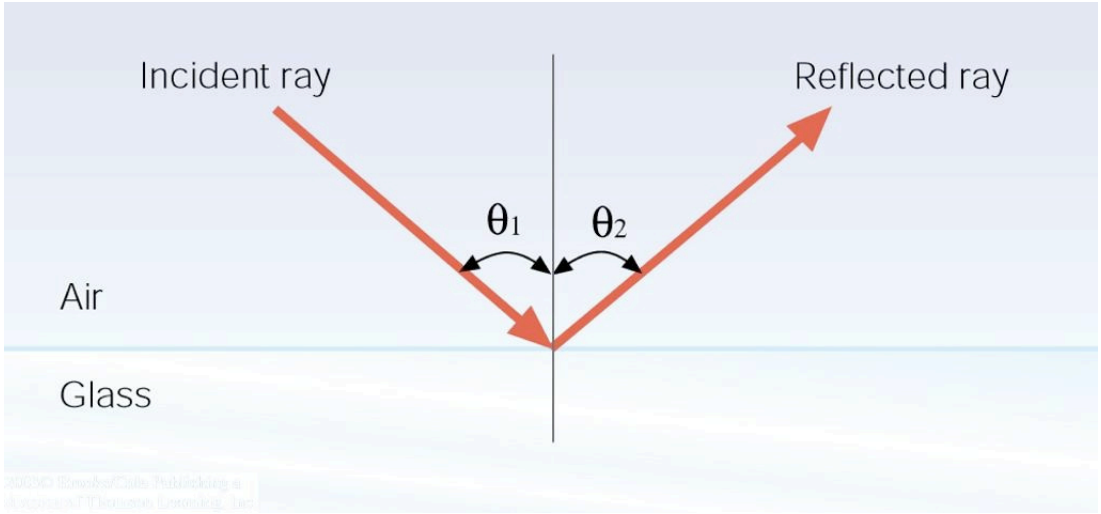
- **Aerosol and Hydrometer Particle Scattering**

- **Particle Scattering: Redirection of radiation by a particle without a loss of energy to the particle**

  1. **Reflection**
  2. **Refraction**
  3. **Diffraction**

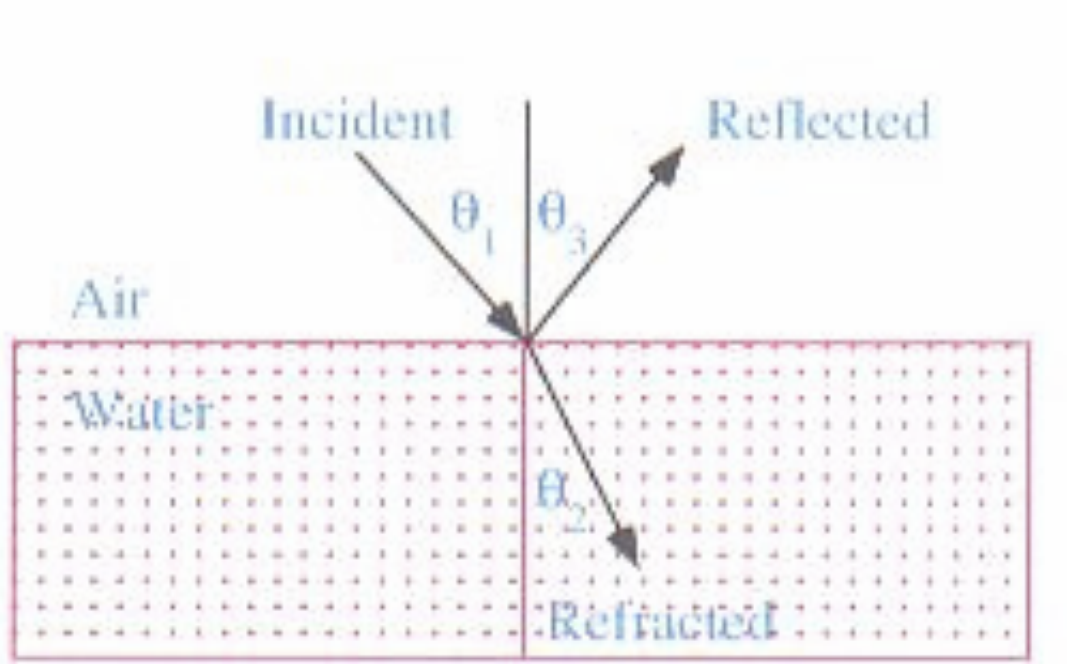
Aerosol Scattering

- **Particle Scattering: redirection of radiation by a particle without a loss of energy to the particle**
- **Reflection: When sunlight bounces off a surface at the same angle at which it strikes the surface, we say that the light is reflected, and call this phenomenon reflection.**
- **The angle of incidence equals the angle of reflection**



Aerosol Scattering

- **Refraction:**
  1. Change of medium of different density
  2. Speed of wave changes
  3. If wave travels into a medium of higher density it refracts toward the surface normal



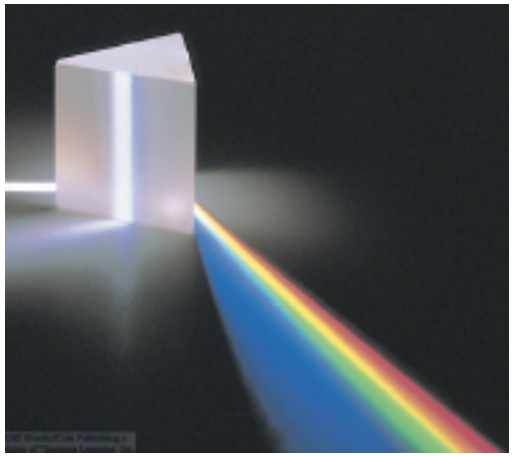
Aerosol Scattering

- **Refraction depends on wavelength**

1. **Refraction bends short wavelengths (e.g. blue) more than long wavelengths (e.g. red).**
2. **Examples for refraction:**

   --- Dispersion of white light into individual colors through a glass/ice crystal prism

   --- Refraction of starlight by the atmosphere



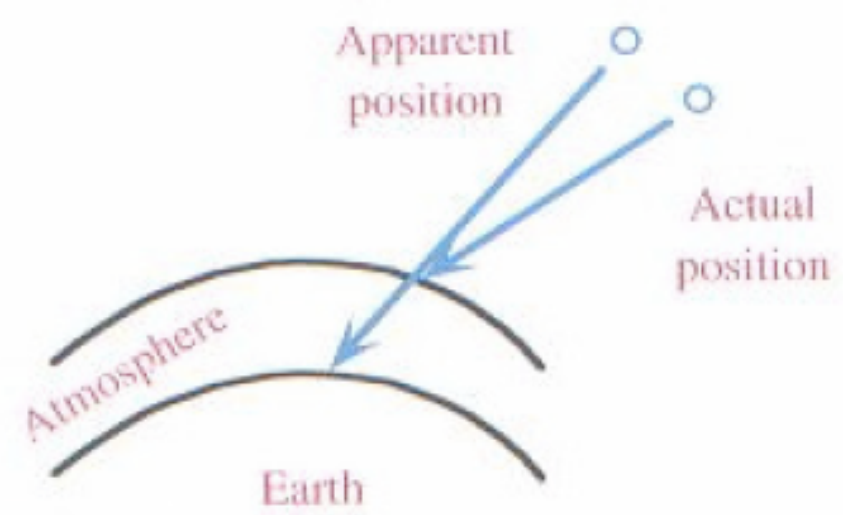
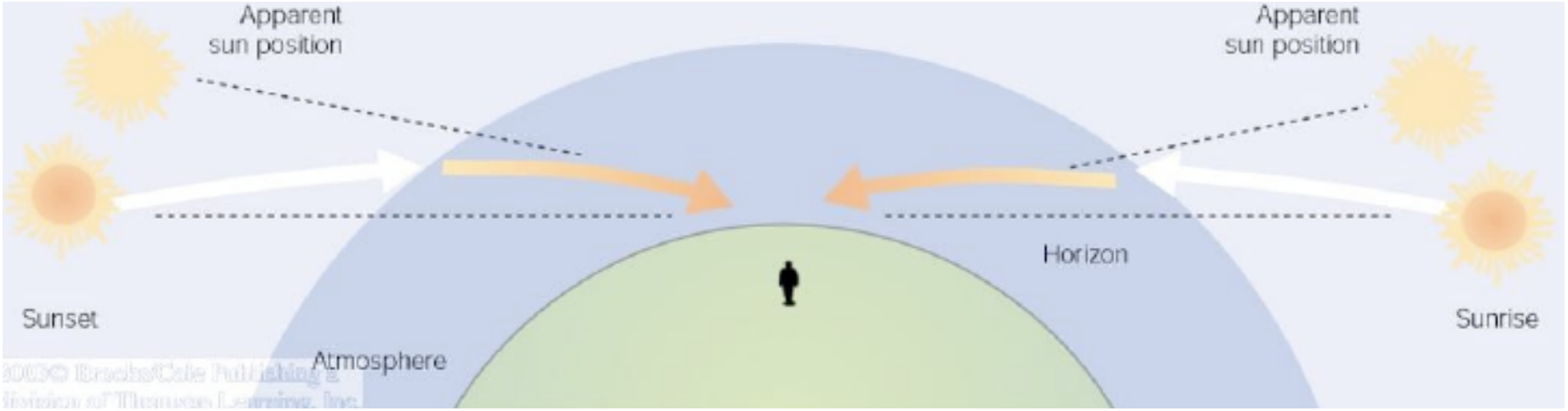


Figure 7.13. Refraction of starlight by the atmosphere makes stars appear to be where they are not.

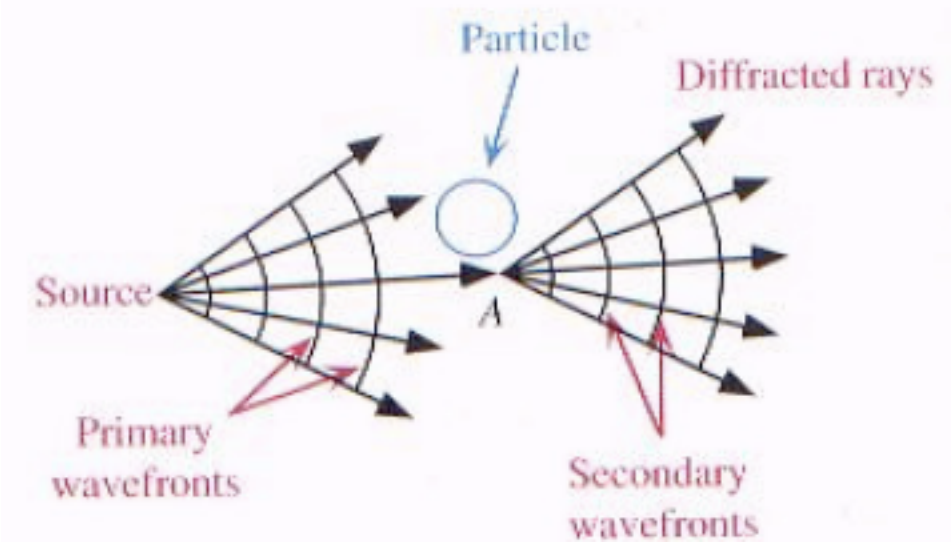
Aerosol Scattering

- **Special case: Refraction & Twilight**
- **Refraction, or bending, of sunlight creates an apparent early sunrise and late sunset.**
- **The amount of extra daylight increases with latitude during Northern summers.**



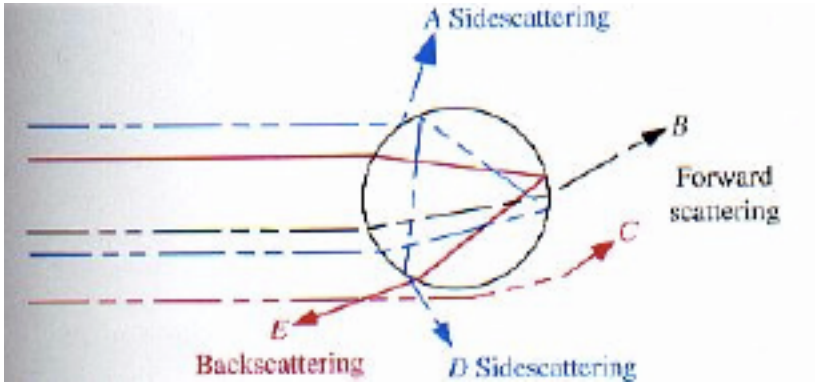
Aerosol Scattering

- **Diffraction:**
- **Wavefront encounters an object causing series of secondary concentric waves**
- **Waves overlap**
- **Bending of light**



Aerosol Scattering

- **Particle Scattering: redirection of radiation by a particle without a loss of energy to the particle.**



- **Diffraction (C) and double refraction (B)**
- **Particle scatter light primarily in the forward direction.**
- **Single internal reflection (E): Backscattering**

Aerosol Scattering

- **Rainbow**

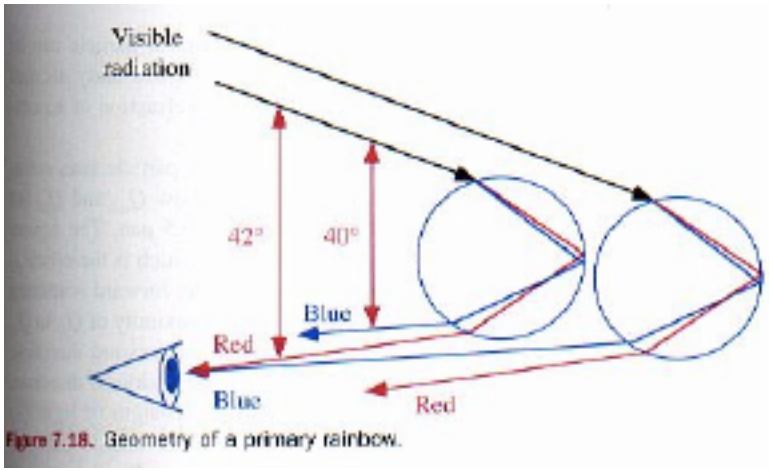
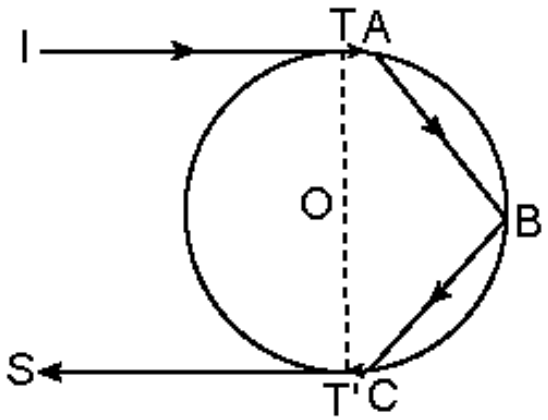


Figure 7.18. Geometry of a primary rainbow.

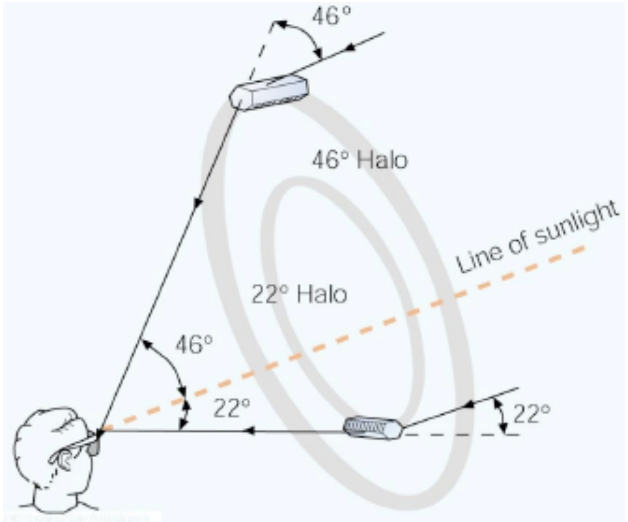
- **Dispersive refraction**
- **Reflection**
- **Viewer's eye only sees one wavelength from each raindrop**

Glory



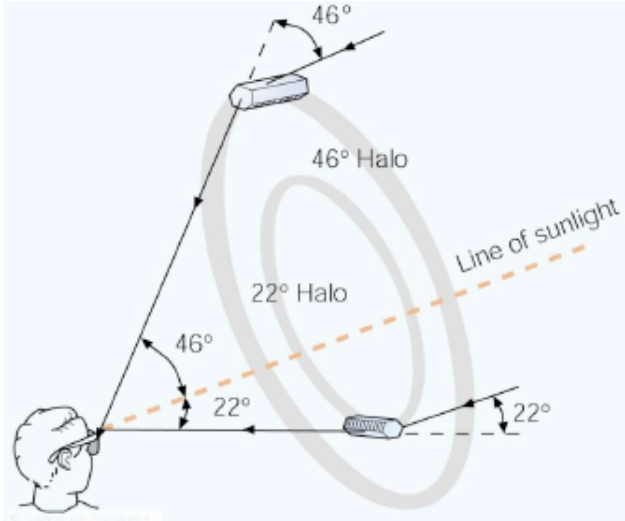
- **When an aircraft flies above a cloud layer composed of tiny water droplets, a set of colored rings called glory may appear around the shadow of the aircraft.**
- **Sunlight that enters the small water droplet along its edge is refracted, then reflected off the backside of the droplet. The light then exits at the other side of the droplet, being refracted once again.**
- **The colorful rings may be due to the various angels at which different colors leave the droplet.**

22° halo



- **A ring of light encircling and extending outward from the sun or moon is called a halo.**
- **Such a display is produced when sunlight or moonlight is refracted as it passes through ice crystals.**
- **Presence of a halo indicates that cirriform clouds are present.**
- **Most common type of halo is the 22° halo -- a ring of light 22° from the sun or moon. It is formed when tiny suspended column-type ice crystals (diameters < 20 micrometers) become randomly oriented as air molecules constantly bump against them.**

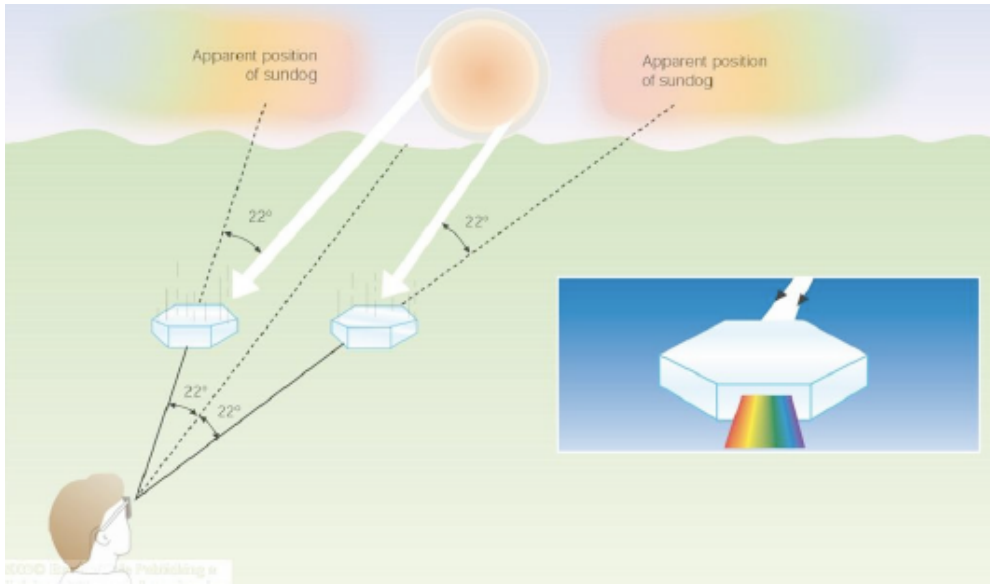
46° halo



22° halo

- **Less common type of halo is the 46° halo. It is formed when light is refracted through column-type ice crystals (diameters between 15 and 25 micrometers).**

Sundog



- **Ice crystals act as small prisms, refracting and dispersing sunlight that passes through them.**
- **If the sun is near the horizon, ice crystals and observers are all in the same horizontal plane. The observer will see a pair of brightly colored spots, one on either side of the sun. These colored spots are called sundogs or parhelia.**

Aerosol Scattering

- **Particle Scattering and Absorption Extinction Coefficients**
- **Cloud water droplets are poor absorbers of light, but large enough to reflect all wavelengths as geometric scatters.**
- **By scattering all visible wavelengths the cloud creates a white passage of light.**
- **Thick clouds, however, diminish the passage of light, and appear dark.**