Visibility and Colors in the Atmosphere

Processes affecting solar radiation in the atmosphere

Visible light from the sun (0.4 – 0.7 μm):

- provides most of the energy that keeps Earth warm
- affects the distance we can see
- affects the colors in the atmosphere
- our vision peaks at 0.55 μm, which is near the sun's peak radiation intensity (Wien's law)

When radiation passes through the Earth's atmosphere, it is attenuated or redirected by **absorption** and **scattering** by gases, aerosol particles, and hydrometeor particles (clouds droplets).

Absorption: radiative energy enters a substance (gas molecule or particle) and is converted to internal energy

→ increases the temperature of the substance
→ reduces the amount of radiation (attenuation)

Scattering: redirection of radiation by a substance (gas molecule or particle) without a net transfer of energy to the substance

Extinction: the attenuation of light due to scattering and absorption as it passes through a medium

Extinction coefficient: a measure of the ability of particles or gases to absorb and scatter photons from a beam of light; proportional to the number of photons removed from the sight path per unit length.

Gas absorption:
Gases selectively absorb radiation in different parts of the electromagnetic spectrum. Ozone, molecular oxygen, and molecular nitrogen are most important for absorbing UV radiation and preventing this from reaching the surface of the Earth. Other gases, such as carbon dioxide (CO_2) or nitric acid (HNO_3) also absorb UV radiation, but their mixing ratios are too low to have much of an effect on the amount of UV light reaching the surface. The only gas that absorbs visible radiation sufficiently to affect visibility is nitrogen dioxide (NO_2).

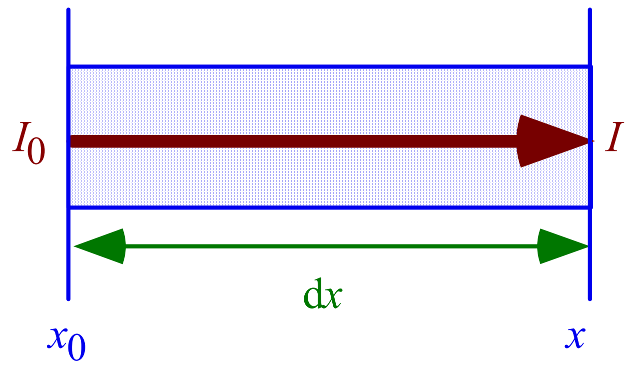

Figure 7.2

Gas scattering: incident radiation is redirected symmetrically in the forward and backwards direction, and somewhat off to the side.

Rayleigh scattering: the scattering of gas molecules or aerosol particles much smaller than the wavelength of light. Because gas molecules are on the order of 0.0005 µm in diameter, while the typical wavelength of visible light is 0.5 µm, all gas molecules are Rayleigh scatterers. Molecular nitrogen (N_2), molecular oxygen (O_2), argon (Ar) and water vapor (H_2O) are the most important scatterers because of their abundance.

Blue sky: blue wavelengths are preferentially scattered by air molecules
White sun at noon:

- Sun's rays travel the shortest distance through the atmosphere
- Some blue light is scattered, but not enough to notice when looking at the Sun

Yellow sun in the afternoon:

- Light takes a longer path through the atmosphere than at noon
- More blue and some green light is scattered out of the direct solar beam
- Although a single gas molecule is more likely to scatter blue than green light, the number of gas molecules along a viewer's line of sight is large enough so that green scattering also becomes significant

Red sun at sunset:

- Sunlight traverses its longest distance through the atmosphere
- Blue, green and some red wavelengths are scattered

Aerosol and Hydrometeor Particle Absorption
All aerosol and hydrometeor particles absorb infrared (IR) radiation, but only a few absorb visible and UV radiation.
Aerosol particle absorbers in the UV portion of the radiation spectrum

- black carbon (soot)
- Components of dust aerosols
- Some organic compounds

- Sea-spray (weak absorber)
- Sulfuric acid ($H_2SO_{4(aq)}$) (weak absorber)

From picture below:
The amount of absorption depends on:

- The type of particle (i.e. soot versus dust)
- The size or diameter of the particle
- The wavelength of light hitting the particle.

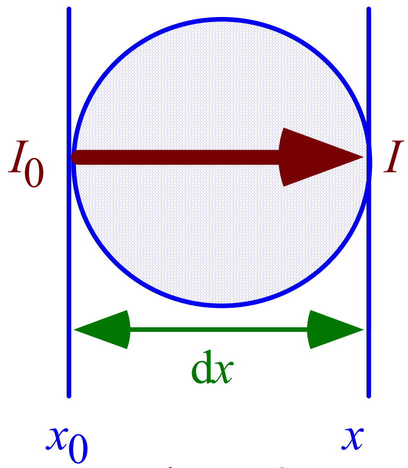

Figure 7.9

Aerosol and hydrometeor particle scattering
Particle scattering is the combination of several processes:
→**Reflection**: Radiation bounces off an object at an angle equal to the angle of incidence. The colors of most objects we see are the result of preferential reflection of certain wavelengths by the object (egg and apple example).

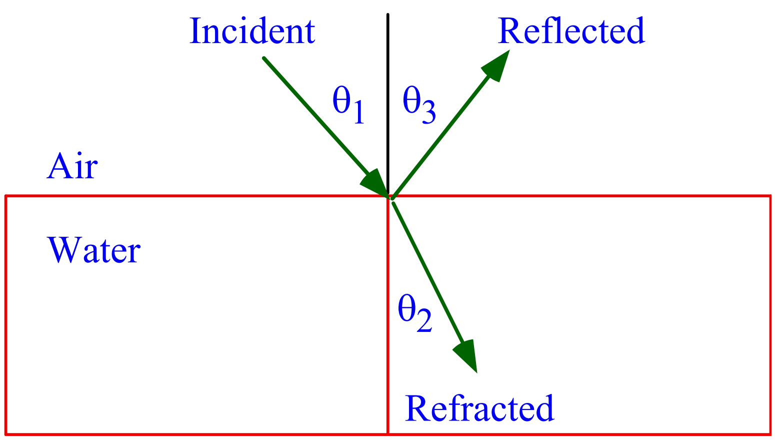

Figure 7.12

→**Refraction**: bending of light. Occurs when a wave leaves a medium of one density (such as air), and enters a medium of another density (such as water). The density change causes the speed of the wave to change, which changes the angle.

→ **Dispersion/Dispersive Refraction**: Separation of white visible light into individual colors by selective refraction. Refraction is wavelength dependent. Different wavelengths are refracted different angles.

→ **Diffraction**: Process by which direction of propagation of a wave changes when the wave encounters an obstruction. Bending of visible light around a particle.

Scattering is a combination of reflection, refraction, dispersion, and diffraction.

<u>Visibility in the Atmosphere</u>

Visibility is a measure of how far we can see through the air. This is affected by light absorption and scattering by particles and gas molecules in the atmosphere.

In clean air, visibility is limited to a few hundred kilometers by background gases and particles.

Meteorological range: regulatory definition of visibility.
Meteorological range: $x = 3.912 / \sigma_t$
$\sigma_t = \sigma_{a,g} + \sigma_{s,g} + \sigma_{a,p} + \sigma_{s,p}$

Importance of Particle Size:
Particles of diameter similar to the wavelength of visible light are the most efficient at scattering sunlight.

EPA's regional haze program (http://www.epa.gov/oar/visibility/program.html)
The EPA has been monitoring visibility in national parks and wilderness areas since 1988. The Regional Haze Rule calls for state and federal agencies to work together to improve visibility in our national parks and wilderness areas.