Lecture 17
Nature's Light Show

Atmospheric Optics
Scattering
Reflection

Ahrens Chapter 15

Atmospheric Optics
Nature's Light Show

Atmospheric Optics

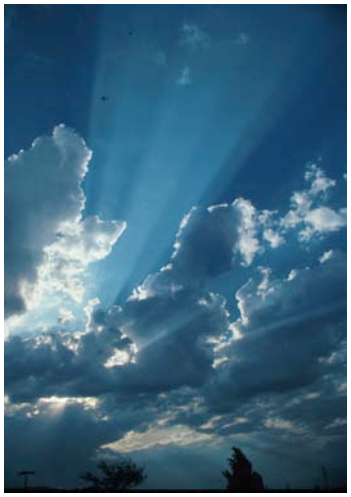
The amazing variety of optical phenomena observed in the atmosphere can be explained by four physical mechanisms.

- Scattering
- Reflection
- Refraction
- Diffraction

Scattering

Things to look for

- Blue Sky
- White Clouds
- Blue Smoke
- Red Sunsets
- Crepuscular Rays
- Heiligenschein



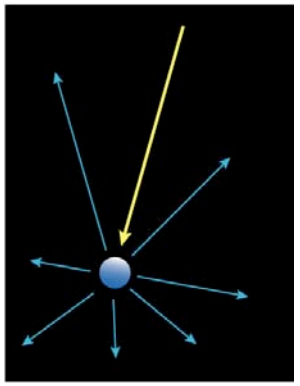
Scattering

Light is scattered by the air molecules, cloud droplets, and aerosols.

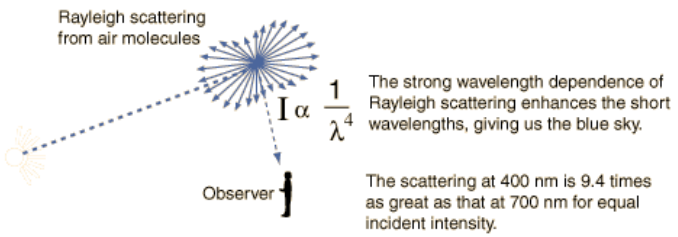
The resulting optics depend on the size of the scatterer.

Scattering

Rayleigh Scattering
Small objects such as air molecules and fine smoke particles most effectively scatter blue light.



Rayleigh Scattering



The strong wavelength dependence of Rayleigh scattering enhances the short wavelengths, giving us the blue sky.

The scattering at 400 nm is 9.4 times as great as that at 700 nm for equal incident intensity.

Scattering of blue light by air molecules is more than 9 times greater than scattering of red light.

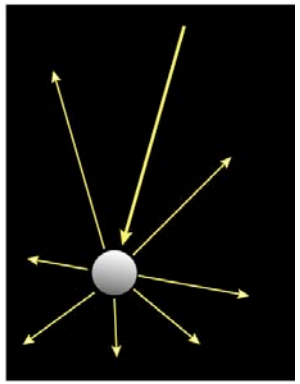
Scattering by Air Molecules

Rayleigh Scattering results in blue sky

Scattering by Air Molecules

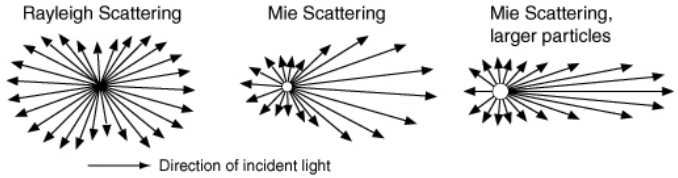
Scattering

Mie Scattering
Larger objects such as cloud droplets and ice crystals scatter all visible light equally well.



Mie scattering is greatest parallel to incident light.

Scattering

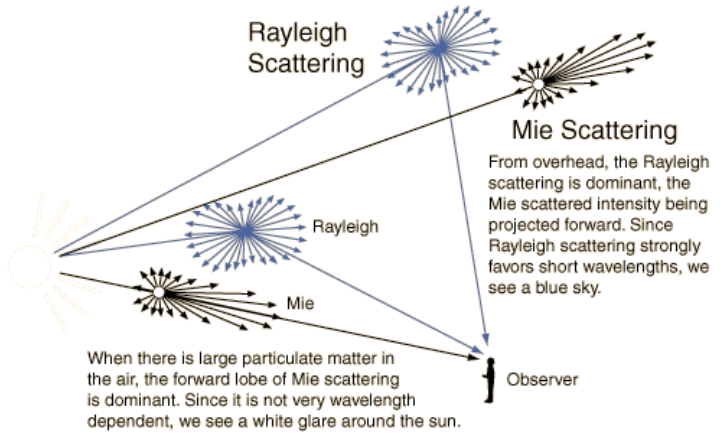


Mie scattering is greatest parallel to incident light.
Rayleigh scatter is nearly equal in all direction.

Scattering by Air Molecules and Clouds

Scattering by Air Molecules and Aerosols

Rayleigh and Mie Scattering



Rayleigh and Mie Scattering

Mie scattering results in white clouds and the glare around the sun. Blue sky is the result of Rayleigh scattering.

Scattering by Smoke

Larger particles appear brown and smaller particles scatter blue.

Scattering by Cloud Droplets

Mie scattering results in white clouds, with black bottoms if they are thick enough.

Avoid exposed places during thunderstorms

Red Sunsets

Most of the blue light is scattered out, leaving red light, which is scattered toward the observer by clouds.

Scattering by Cloud Particles

Scattering by Cloud Particles

When the sun sets or rises, the sunlight passes through a long path of air. Most of the blue light is scattered out, leaving red light, which is scattered toward the observer by clouds.

Scattering by Aerosols

Crepuscular Rays

Scattering by Aerosols

Crepuscular Rays

Scattering by Aerosols

Crepuscular Rays

Scattering by Cloud Droplets

Crepuscular Rays

Crepuscular Rays

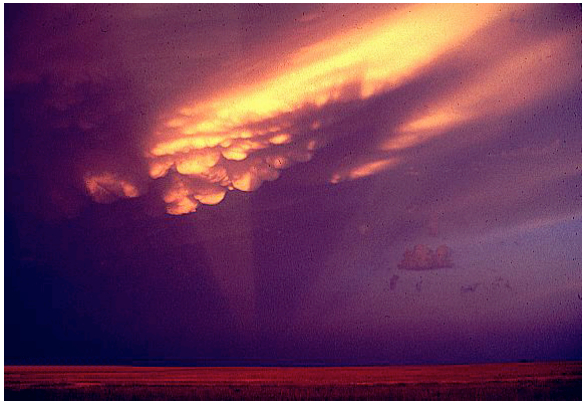
Shadows cast by clouds or trees on hazy days result in crepuscular rays, also known as Jacob's ladders.

Crepuscular Rays

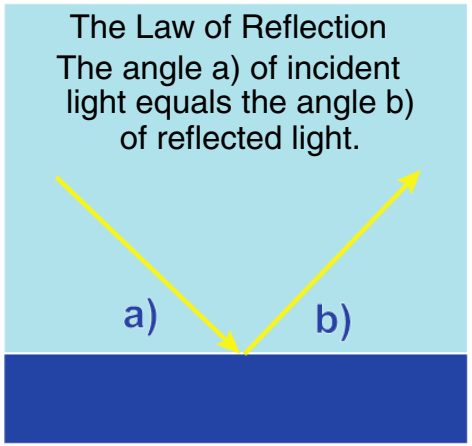
Crepuscular Rays

Mountain's Shadow

Anti-crepuscular Rays



Reflection



Reflection

- Sun Pillars
- Circumhorizontal Arcs

Reflection by Water

Reflection by Water

Reflection by Water

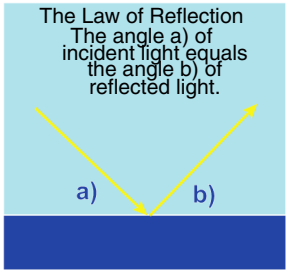
Reflection by Water

Reflection by Water

Sunlight reflecting off of the ocean can produce a sun pillar.

Reflection by Ice Crystals

Sun Pillars

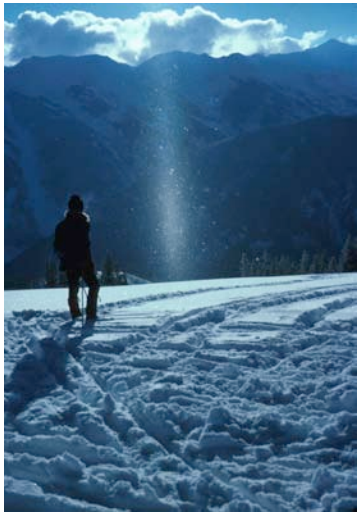


Reflection by Ice Crystals

Sunlight reflecting off of plate-shaped ice crystals can produce a sun pillar.

Reflection by Ice Crystals

Sun pillar



Reflection by Ice Crystals

Sun pillars commonly occur beneath an altostratus cloud just after sunset.

Reflection by Ice Crystals

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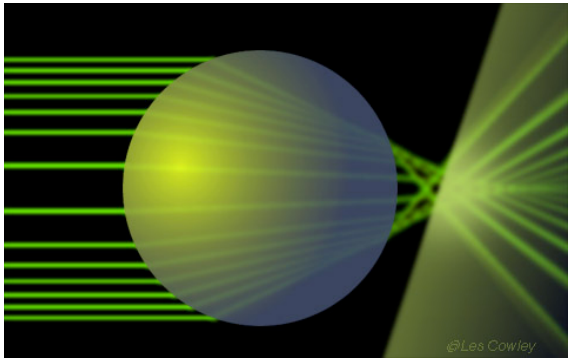
Reflection by Ice Crystals

Sun pillars commonly occur beneath an altostratus cloud just after sunset.

Reflection and Scattering by Dew Drops



Heiligenschein

Reflection and Scattering by Dew Drops

Heiligenschein

Questions?

Atmospheric Optics

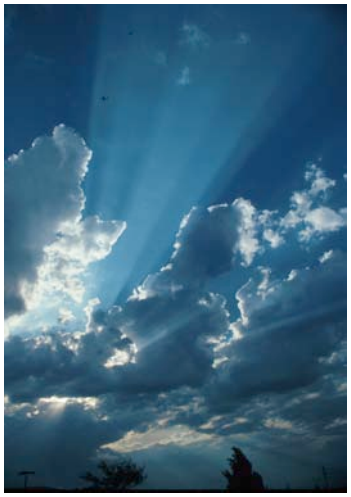
The amazing variety of optical phenomena observed in the atmosphere can be explained by four physical mechanisms.

- Scattering
- Reflection
- Refraction
- Diffraction

Rayleigh and Mie Scattering

Things to look for

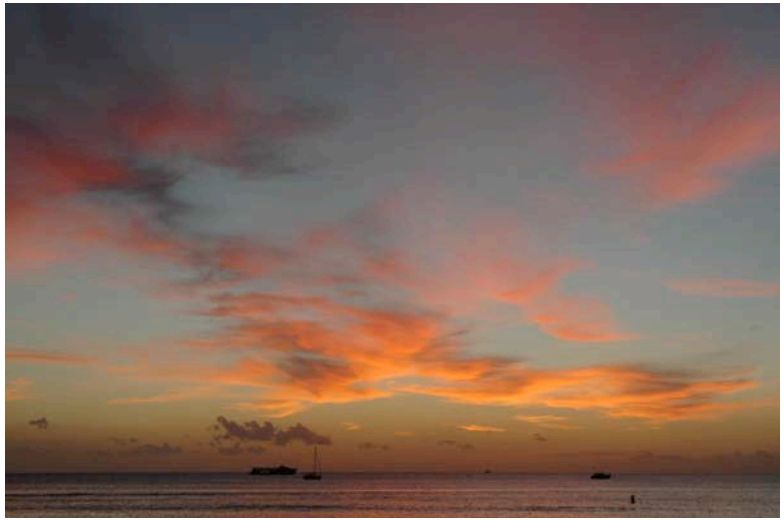
- Blue Sky
- White Clouds
- Blue Smoke
- Red Sunsets
- Crepuscular Rays
- Heiligenschein



Scattering by Cloud Particles

When the sun sets or rises, the sunlight passes through a long path of air. Most of the blue light is Rayleigh scattered out, leaving red light, which is Mie scattered toward the observer by clouds.

Scattering by Cloud Particles

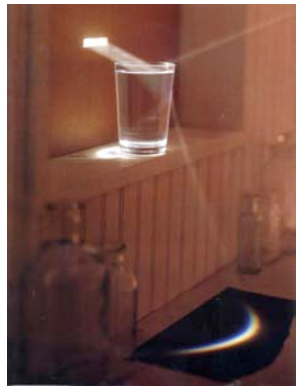


Reflection

- Sun Pillars
- Circumhorizontal Arcs

Refraction

- Green Flash
- Mirage
- Halo
- Tangent Arc
- Rainbow



Refraction

Light slows down as it passes from a less dense to a more dense medium.

As light slows it bends toward the denser medium. Similar to waves approaching a beach.

The amount of bending depends on the wavelength (color) of the light, leading to dispersion or separation of colors.

Refraction in Air

Mirage

Refraction in Air

Mirage

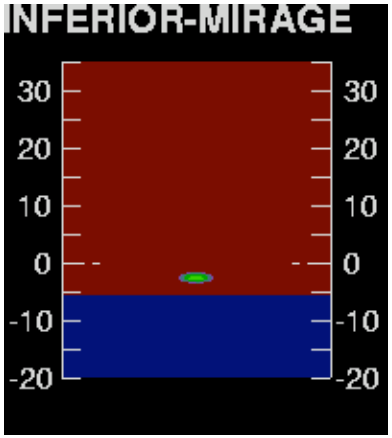
Refraction in Air

Green Flash

Refraction in Air

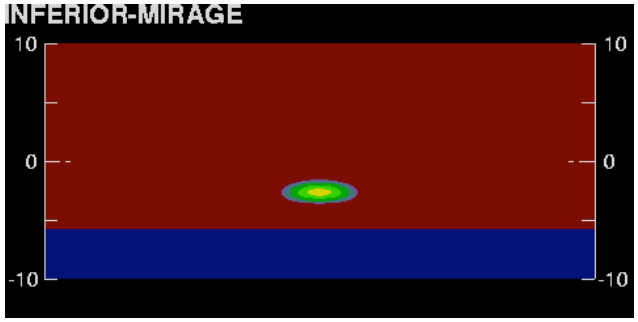
Green Flash

Refraction in Air



Green Flash

Refraction in Air



Green Flash

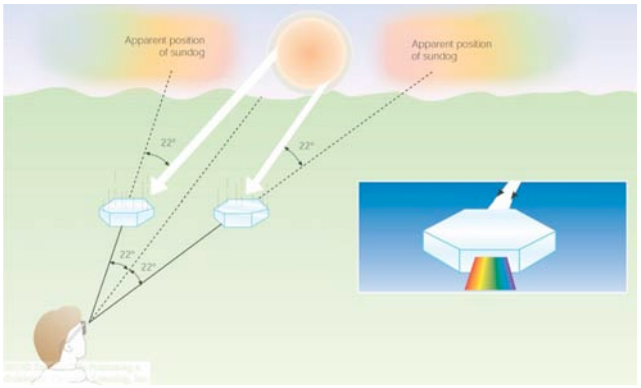
Refraction in Air

Red Flash

Refraction by Ice Crystals

22 1/2˚ Halo

Refraction by Ice Crystals

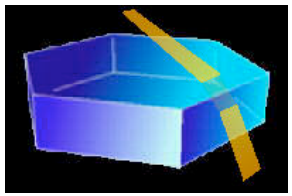


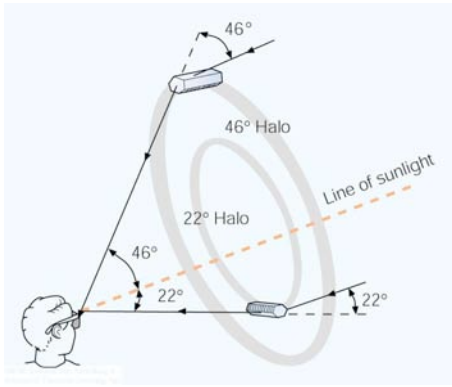
Sun Dogs

Refraction by Ice Crystals

Sun Dog

Refraction by Ice Crystals





22 1/2˚ Halo

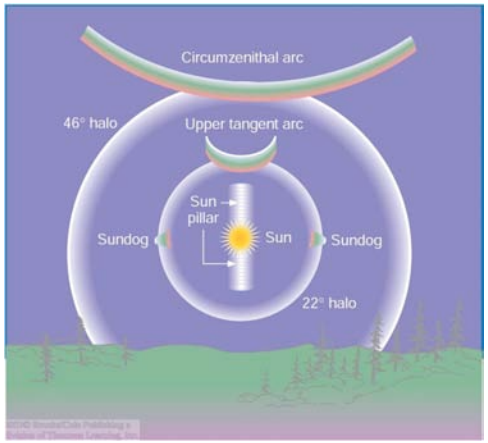
Refraction by Ice Crystals

22 1/2˚ Halo and Upper Tangent Arc

Refraction by Ice Crystals

22 1/2˚ Halo

Refraction by Ice Crystals



Halo Complex

Refraction by Ice Crystals

Halo Complex

Refraction by Ice Crystals

46˚ Halo?

Refraction by Ice Crystals

Lower Tangent Arc

Refraction by Ice Crystals

Lower Tangent Arc

Refraction and Scattering

Sun Pillar and Sun Dog?

Atmospheric Optics

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Rayleigh and Mie Scattering

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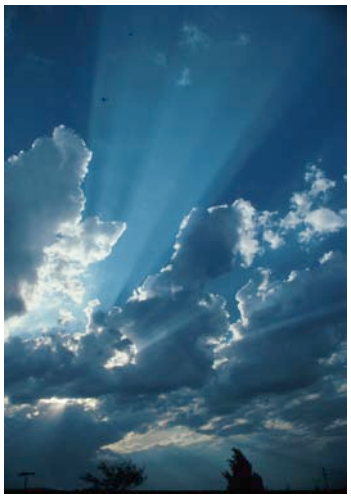


Scattering by Cloud Particles

Rayleigh scattering by air molecules results in a blue sky. Mie scattering by droplets results in white/grey clouds.

Scattering by Cloud Particles

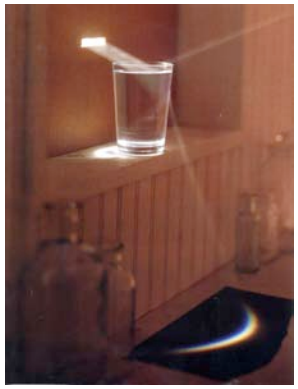
When the sun sets or rises, the sunlight passes through a long path of air. Most of the blue light is Rayleigh scattered out, leaving red light, which is Mie scattered toward the observer by clouds.

Reflection

- Sun Pillars
- Circumhorizontal Arcs

Refraction

- Green Flash
- Mirage
- Halo
- Tangent Arc
- Rainbow



Refraction

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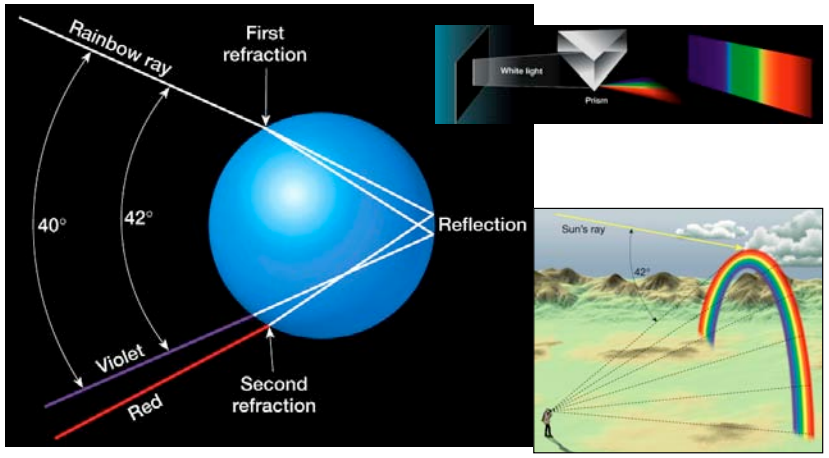
Refraction Causes

Mirage
Green Flash
Halos
Sundogs
Rainbows

Halo Complex results from refraction by ice crystals

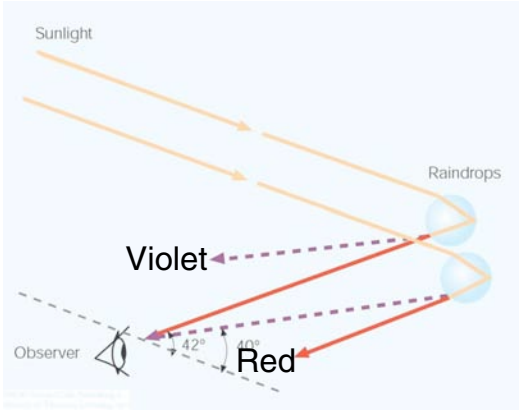
Refraction by Water Drops

Refraction by Water Drops



Refraction by Rain

Refraction by Water Drops

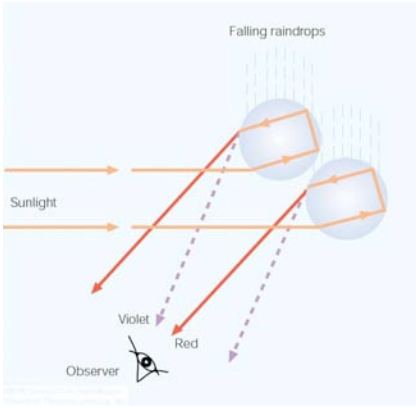


Primary Rainbow

Refraction by Rain

Double Rainbow

Refraction by Rain



Double Rainbow

Refraction by Rain

Partial Rainbow

Refraction by Rain

Double Rainbow

Refraction by Rain

High Sun: Low Rainbow

Refraction by Rain

Rainbow seen from Airplane

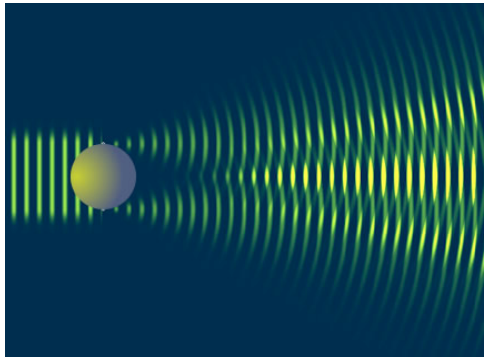
Diffraction

Constructive interference of light waves can produce color separation.

The physical mechanism in this case is called diffraction.

Produces colors on soap films, oil slicks, and music CDs.

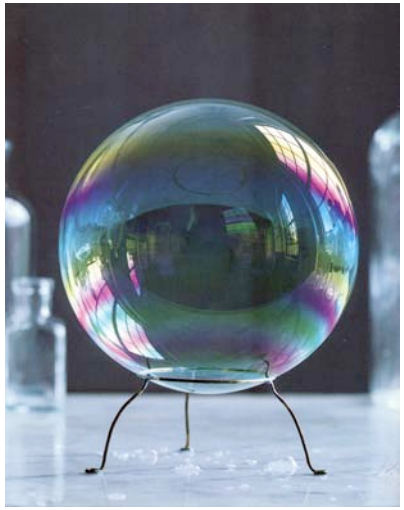
Diffraction causes Interference



Diffraction is the tendency of light waves to bend as they pass the edges of objects.

Diffraction by Soap Film

Diffraction Results in
- Iridescence
- Corona
- Glory
- Supernumerary bows



Diffraction by Cloud Drops

Iridescence

Diffraction by Airplane Window

Artificial Iridescence

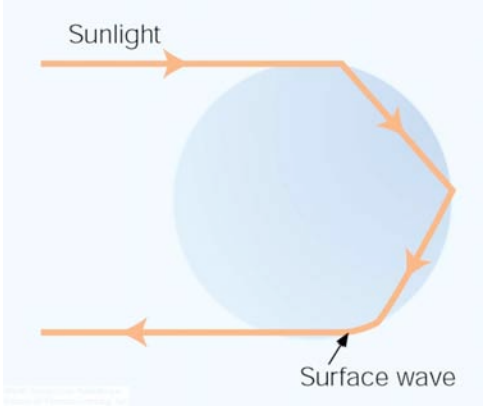
Diffraction by Cloud Droplets

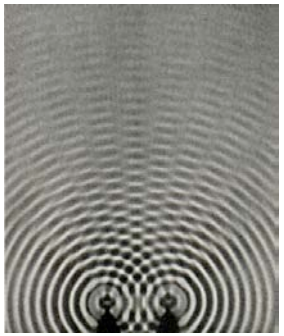
Corona

Diffraction by Pollen

Corona

Diffraction and Reflection





Glory

Diffraction and Reflection

Glory

Diffraction and Reflection

Glory

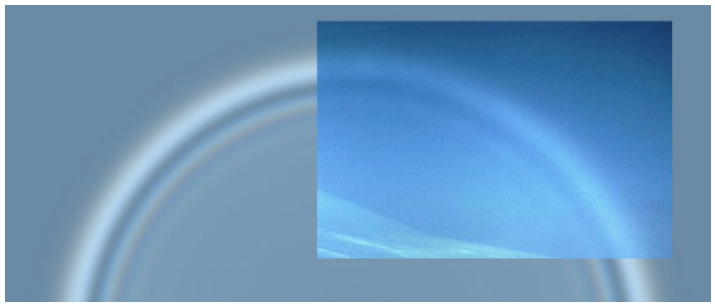
Diffraction and Reflection

Supernumerary Rays

Diffraction and Reflection

Fog Bow: larger drops do not allow dispersion of colors.

Diffraction and Reflection



Fog Bow: larger drops do not allow dispersion of colors.

Summary: Atmospheric Optics

The amazing variety of optical phenomena observed in the atmosphere can be explained by four physical mechanisms.

- Scattering
- Reflection
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- Diffraction