MET 200
Lecture 14
Nature's Light Show

Atmospheric Optics

Ahrens Chapter 15

Vog Bank

Atmospheric Optics

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

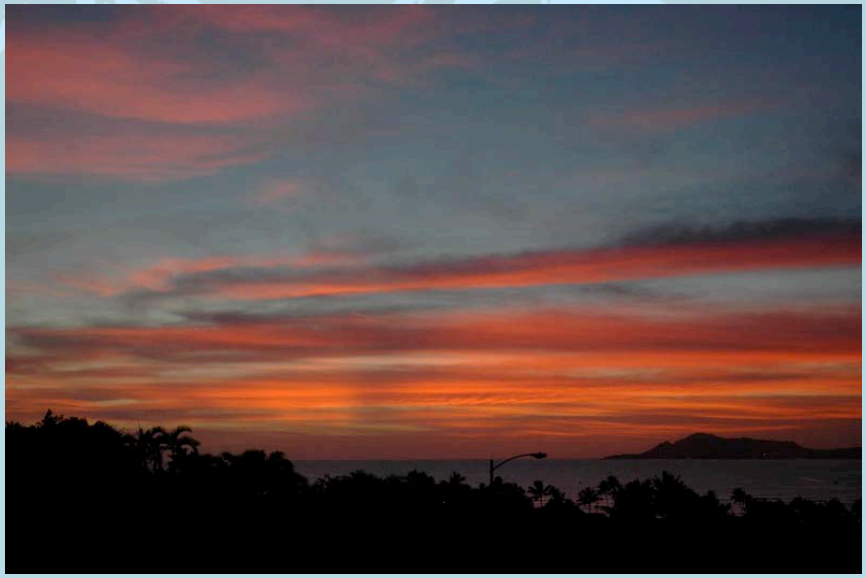
- Scattering
- Reflection
- Refraction
- Diffraction

Scattering

Things to look for

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

Why is this Sunset Red?



Scattering

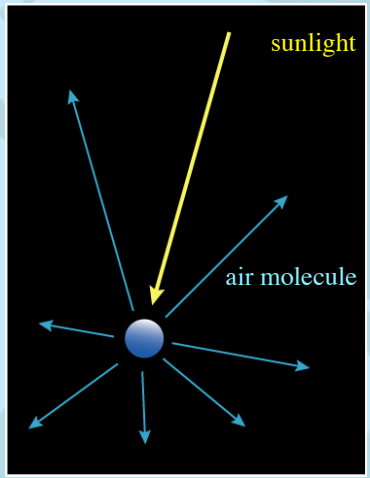
Light is scattered by the air molecules, cloud droplets, and aerosols.

The resulting optics depend on the size of the scatterer.

Scattering

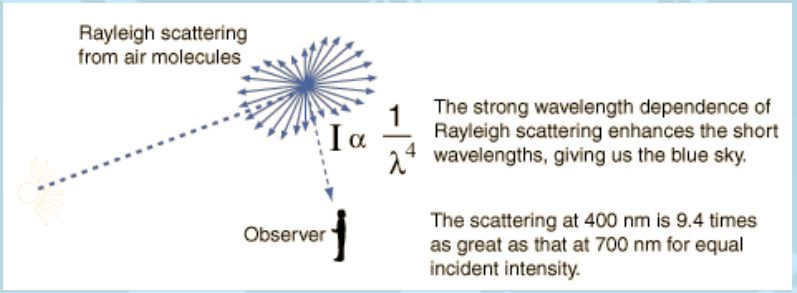
Rayleigh Scattering

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



Rayleigh Scattering is nearly equal in all directions.

Rayleigh Scattering



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

Scattering by Air Molecules

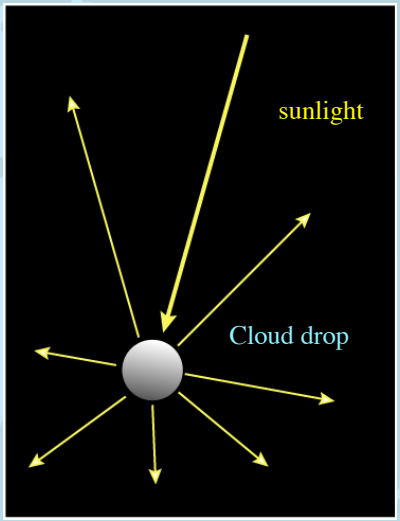
Rayleigh Scattering results in blue sky

Scattering by Air Molecules

Scattering

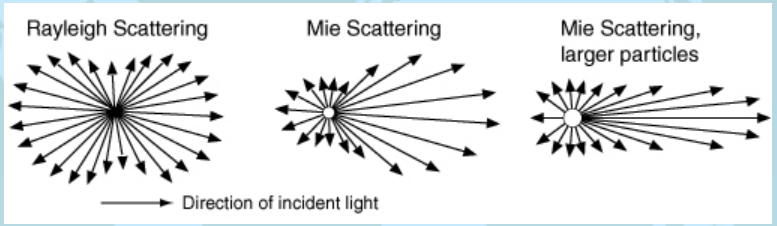
Mie Scattering

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



Mie scattering is greatest parallel to incident light.

Scattering

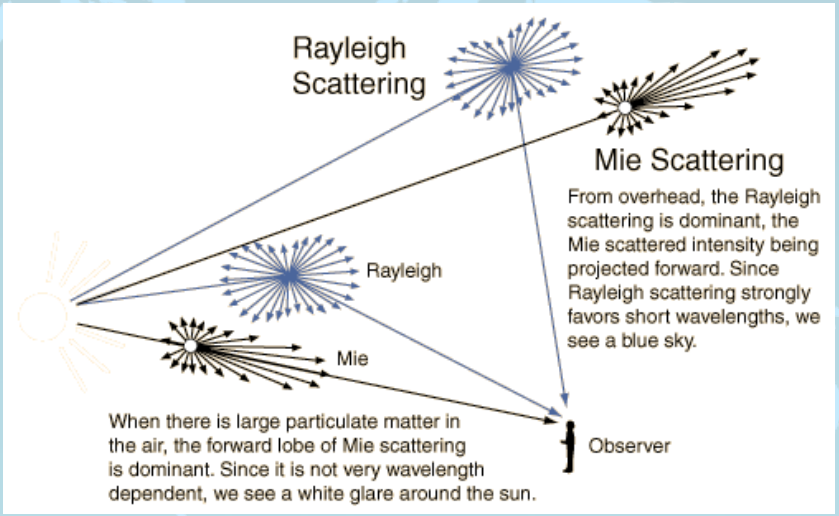


Mie scattering is greatest parallel to incident light. Rayleigh scatter is nearly equal in all directions.

Rayleigh and Mie Scattering

Scattering by Air Molecules and Clouds

Rayleigh and Mie Scattering



Rayleigh and Mie Scattering

Scattering by Air Molecules and Aerosols

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

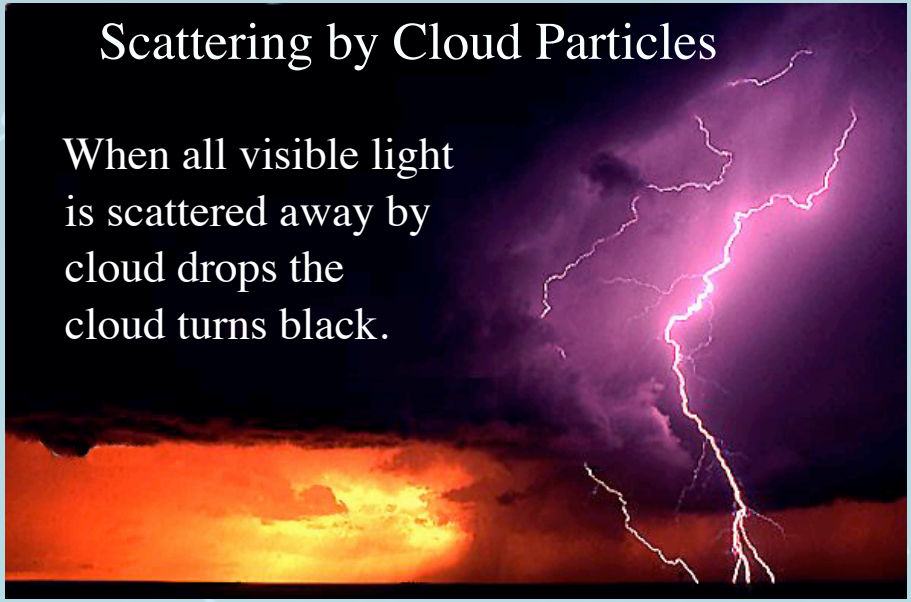
Larger particles appear brown and smaller particles scatter blue.

Scattering by Cloud Droplets

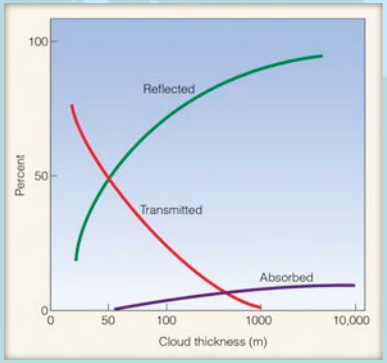
Mie scattering results in white clouds with black bottoms when the clouds are tall enough.

Scattering by Cloud Particles

When all visible light is scattered away by cloud drops the cloud turns black.

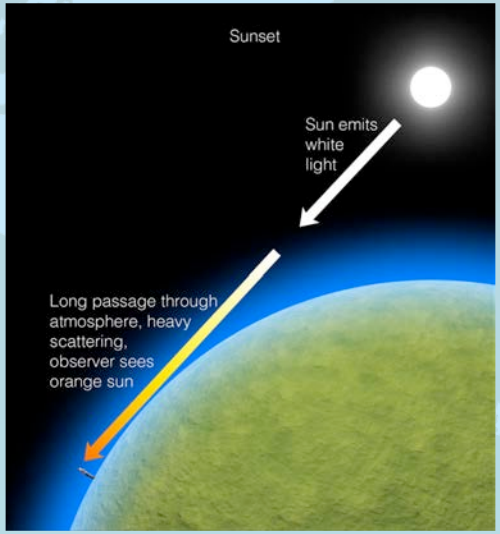


Avoid exposed places during thunderstorms



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

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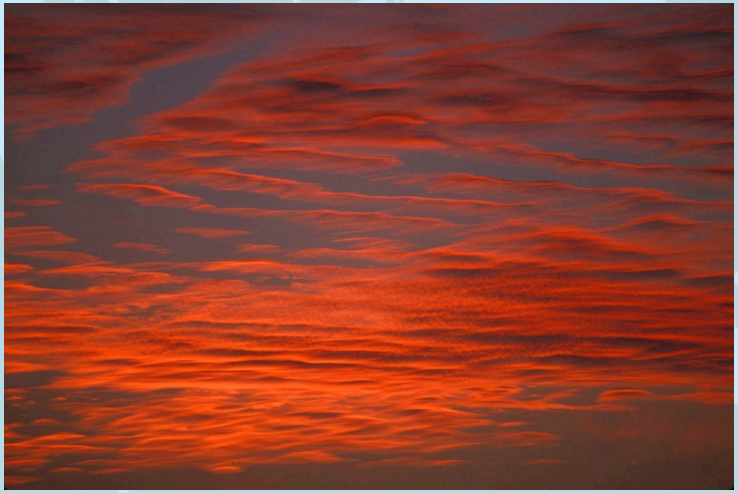
Rayleigh and Mie Scattering

Rayleigh and Mie Scattering

Rayleigh and Mie Scattering



Scattering by Aerosols

Crepuscular Rays

Scattering by Fog Droplets

Crepuscular Rays

Scattering by Fog Droplets

Crepuscular Rays

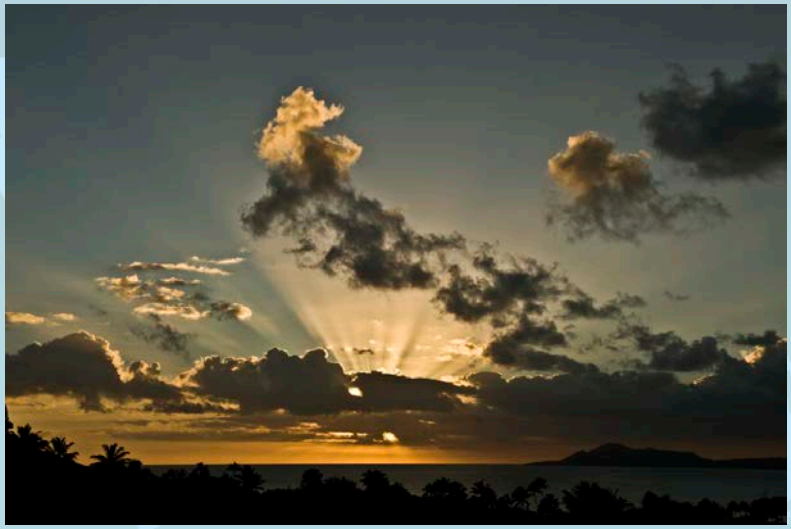
Scattering by Aerosols

Crepuscular Rays

Scattering by Fog Droplets

Crepuscular Rays

Crepuscular Rays

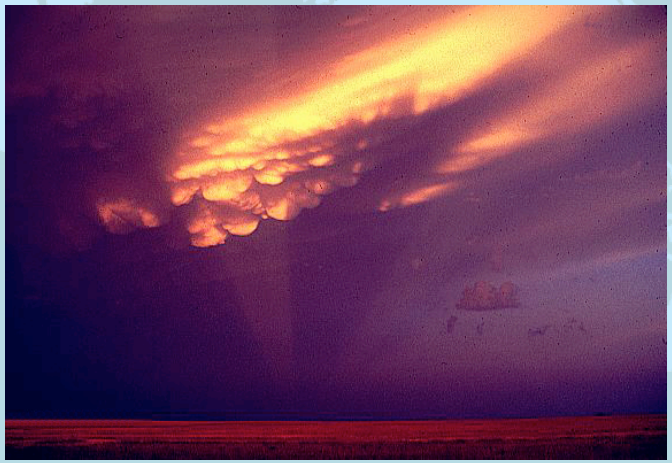


Shadows cast by clouds or trees on hazy days result in crepuscular rays, also known as Jacob's ladders.

Crepuscular Rays

Mountain's Shadow

Anti-crepuscular Rays



Summarizing: Scattering

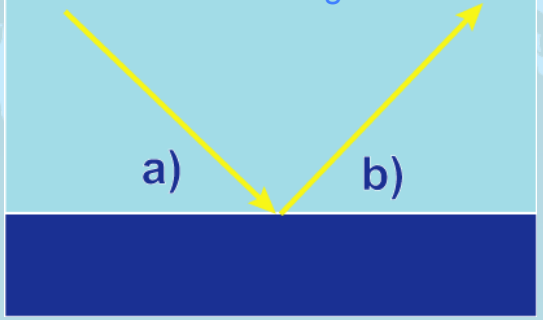
Scattering of light in the atmosphere causes many familiar effects: blue skies, white clouds, hazy days, colorful sunsets, crepuscular rays

Impact of Vog on Sunset

Reflection

The Law of Reflection

The angle a) of incident light equals the angle b) of reflected light.



Reflection

Things to look for:
- Sun Pillars
- Circumhorizontal Arcs

Reflection by Water

Reflection by Water

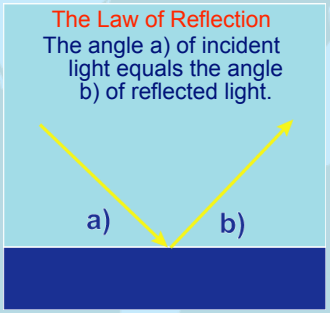
Reflection by Water

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

Reflection by Ice Crystals

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

Reflection by Ice Crystals

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

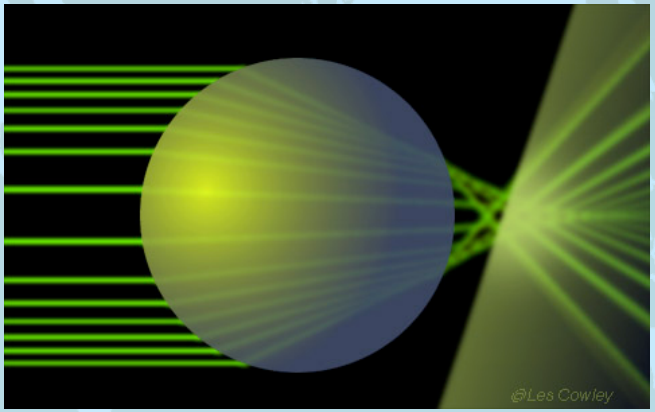
Reflection by Ice Crystals

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

Sun Pillar

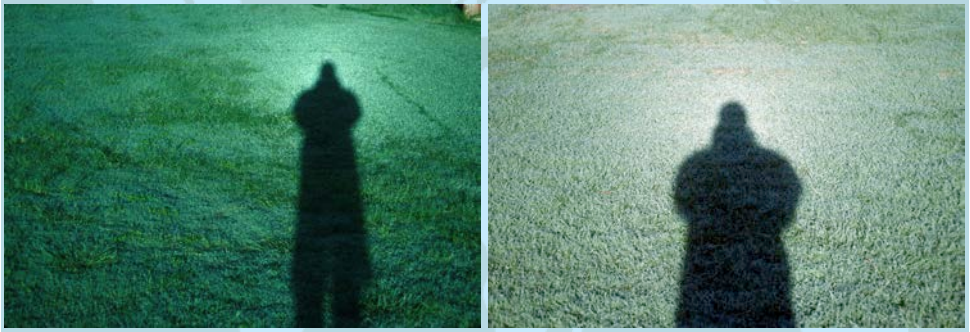
Sun Pillar

Reflection and Scattering by Dew Drops



Heiligenschein

Reflection and Scattering by Dew Drops



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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

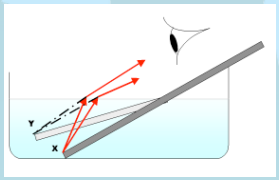
Refraction

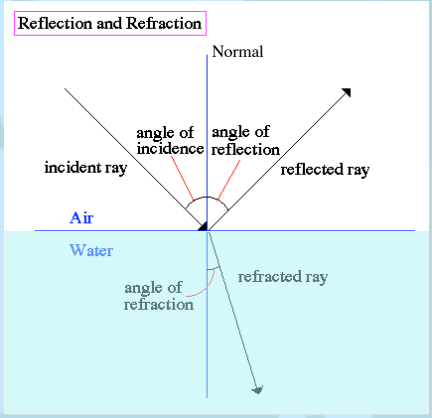
Things to look for:
- Mirage
- Green Flash
- Halo
- Tangent Arc
- Rainbow

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.





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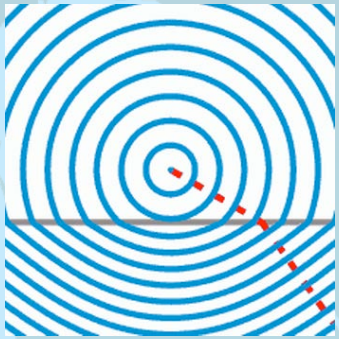
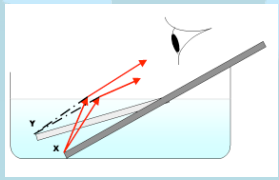
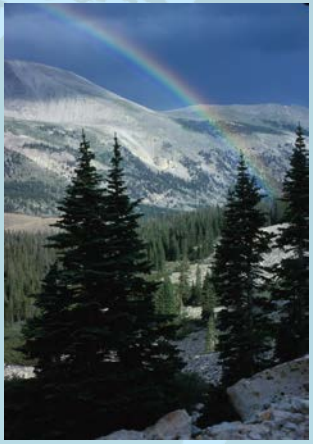
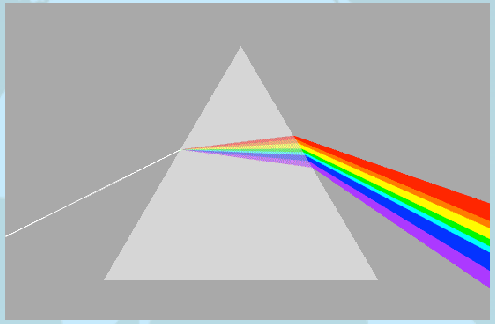




Refraction



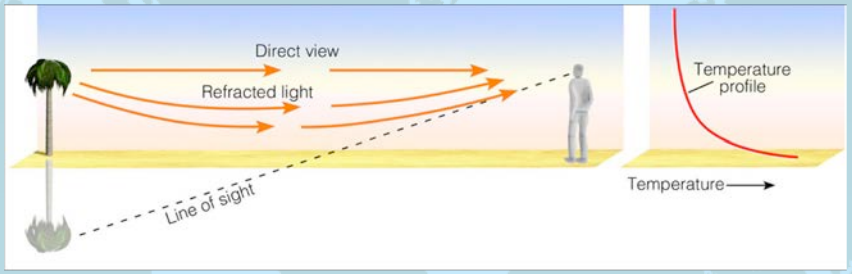


The amount of bending depends on the wavelength (color) of the light, leading to dispersion or separation of colors.

Refraction in Air

Inferior Mirage

Refraction in Air



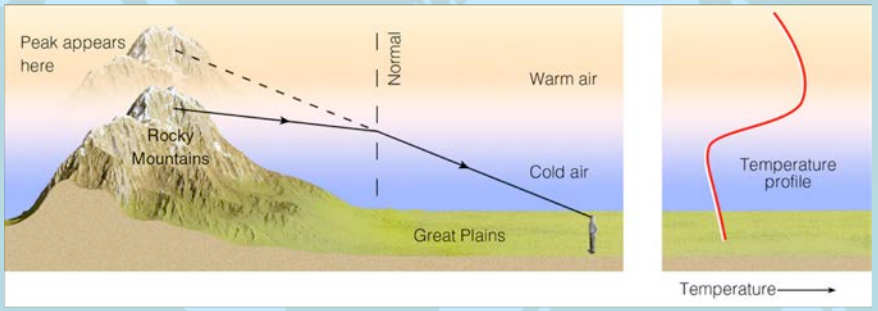
Inferior Mirage

Refraction in Air

Refraction in Air

Superior Mirage

Refraction in Air



Superior Mirage

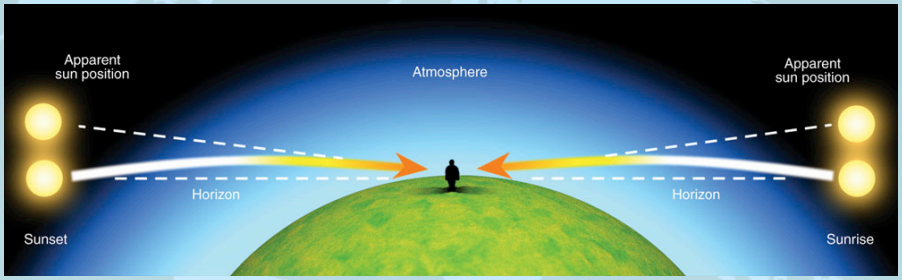
Refraction in Air

Superior Mirage

Refraction in Air

Superior Mirage

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. Note: the atmosphere also refracts the sunlight, which causes red and green flashes.

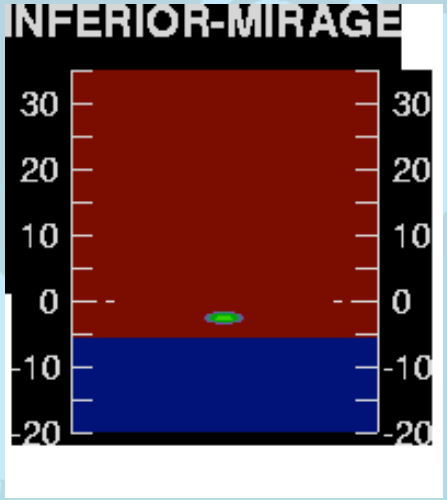
Refraction in Air

Green Flash is a form of superior mirage

Refraction in Air

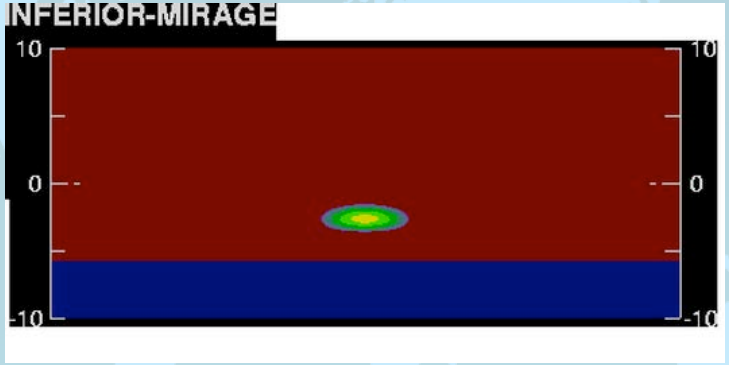
Green Flash

Refraction in Air



Green Flash Animation

Refraction in Air



Green Flash Animation

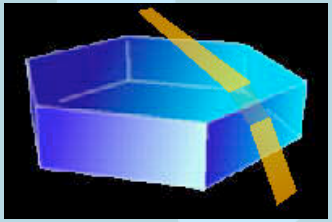
Refraction in Air

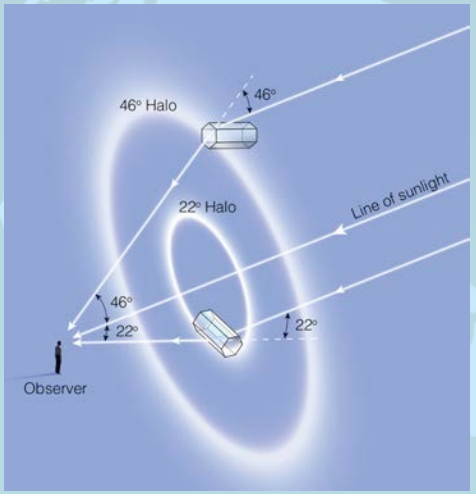
Red Flash

Refraction by Ice Crystals

22 1/2˚ Halo

Refraction by Ice Crystals





22 1/2˚ Halo

Refraction by Ice Crystals

22 1/2˚ Halo

Refraction by Ice Crystals

22 1/2˚ Halo

Refraction by Ice Crystals

22 1/2˚ Halo around the moon

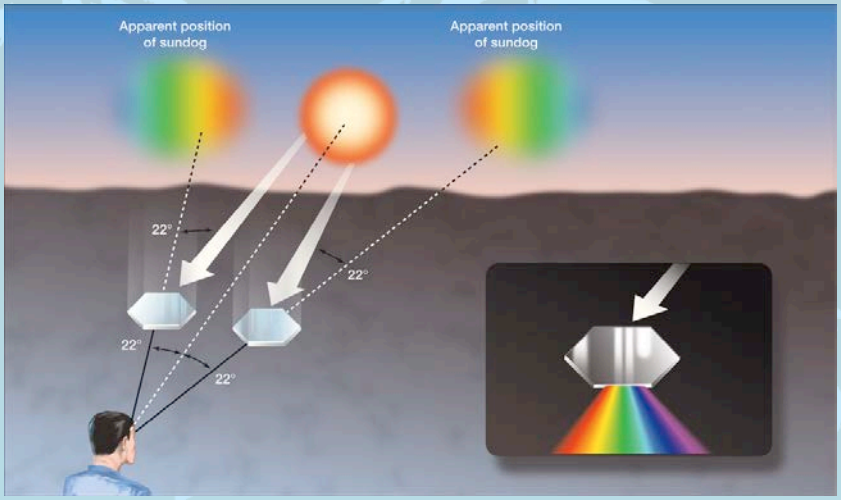
Refraction by Ice Crystals

22 1/2˚ Halo and Upper Tangent Arch

Refraction by Ice Crystals

Halo Complex

Refraction by Ice Crystals

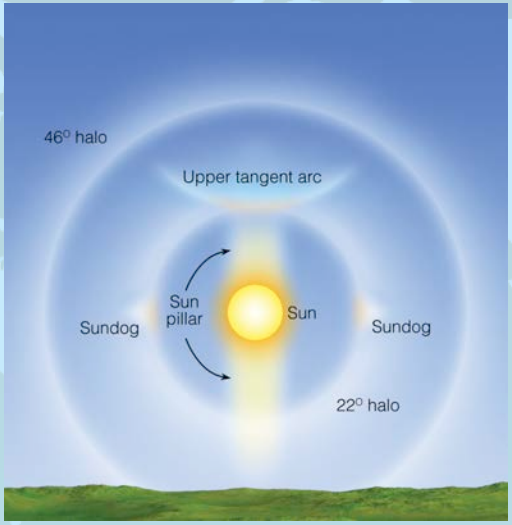


Sun Dogs

Refraction by Ice Crystals

Sun Dogs

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

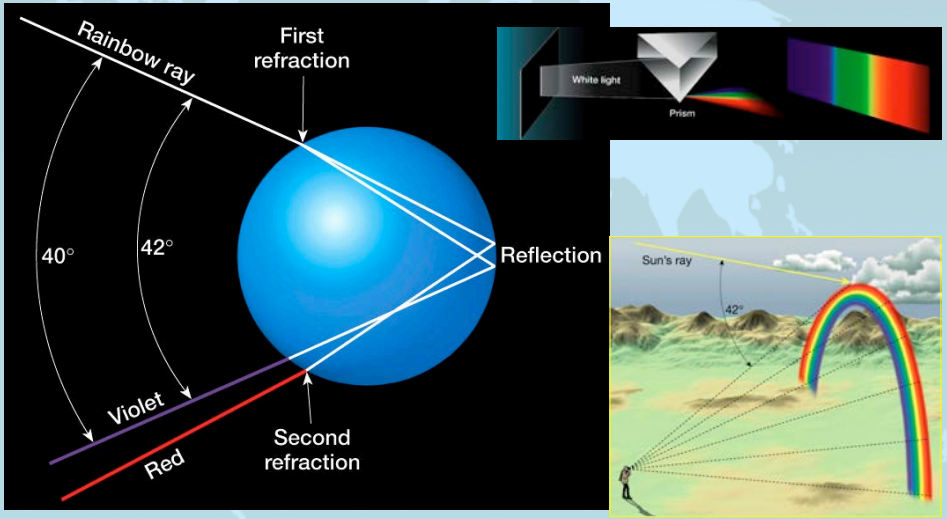
Refraction and Reflection

Sun Pillar and Sun Dog?

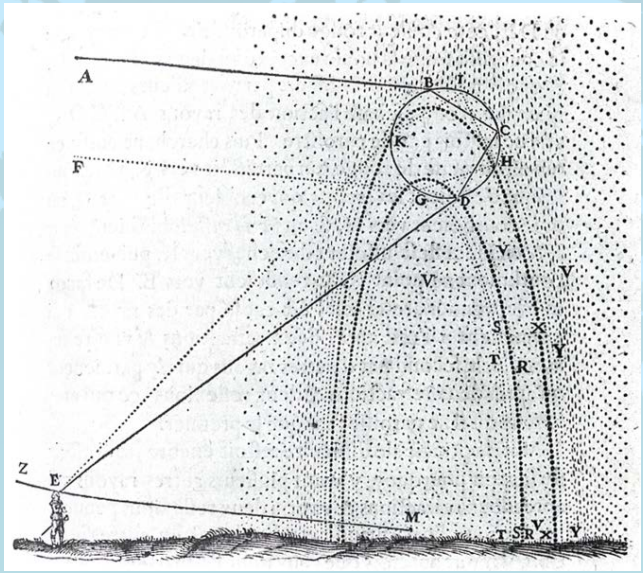
Refraction by Water Drops

Rainbow in Hawaiian is ānuenue

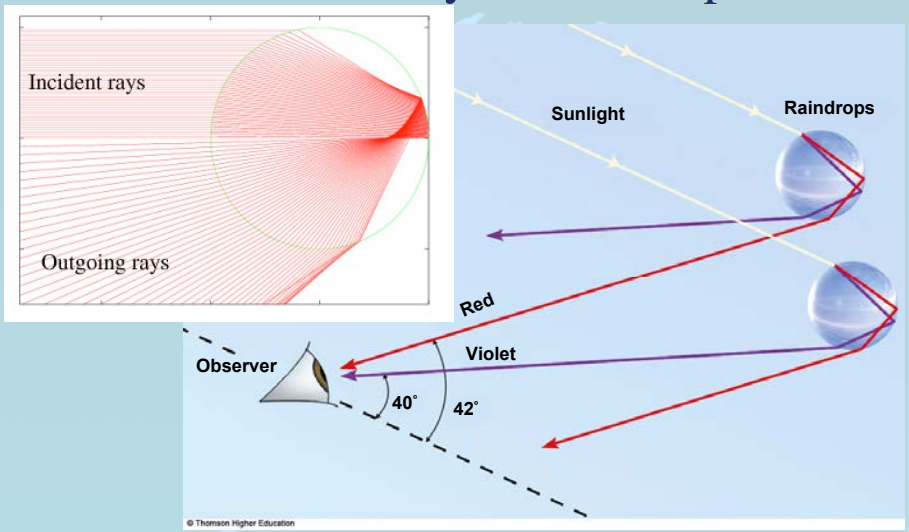
Refraction by Water Drops



Descarte's Schematic



Refraction by Water Drops

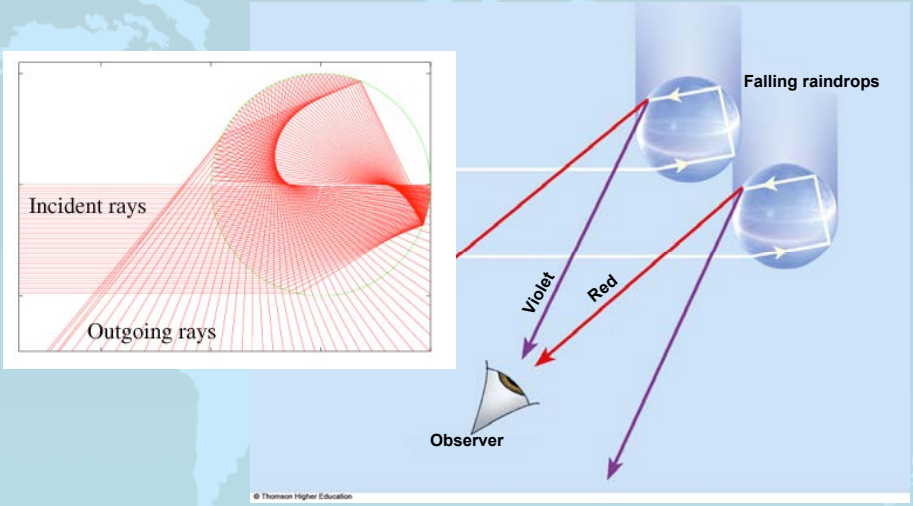


Primary Rainbow

http://punchandbrodie.com/ncyclo/rainbows/

Refraction by Rain

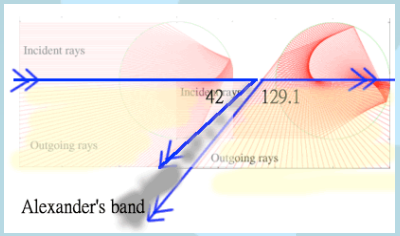
Refraction by Rain



Double Rainbow

Refraction by Rain

Alexander's Dark Band



Refraction by Rain

Double Rainbow

Refraction by Rain

Double Rainbow

Refraction by Rain

High Sun: Low Rainbow

Refraction by Rain

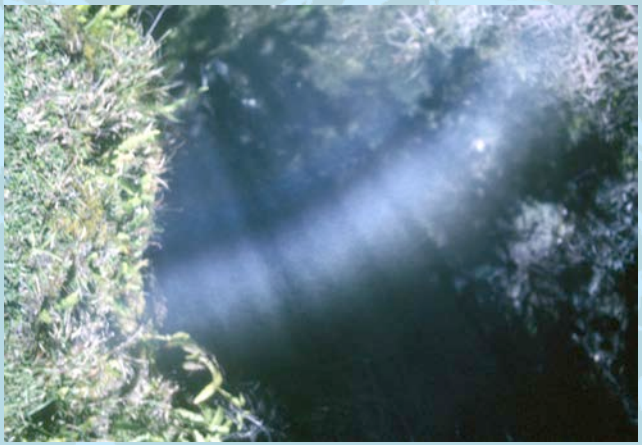
Rainbow seen from Airplane

Low Sun: High Rainbow

Refraction and Reflection

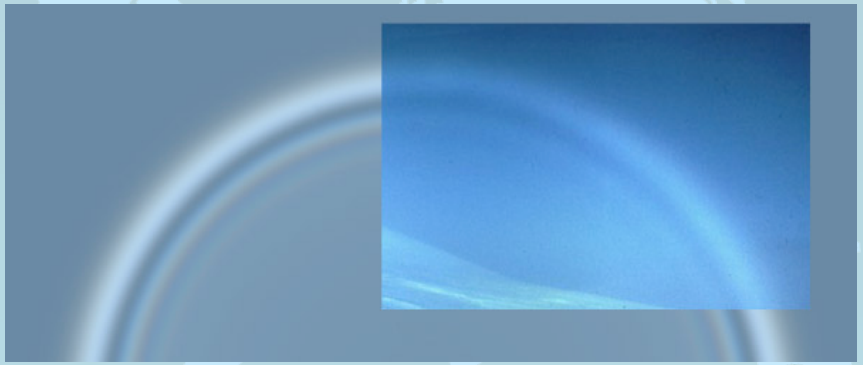
Fog Bow: smaller drizzle droplets reduce the dispersion of colors.

Refraction and Reflection



Fog Bow in Kilauea steam vent: cloud drops do not allow dispersion of colors.

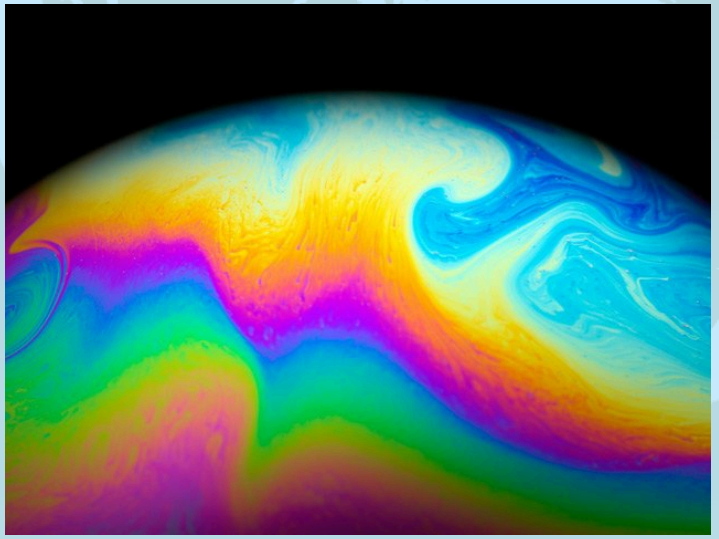
Refraction and Reflection



Fog Bow simulation: small cloud drops do not allow dispersion of colors.

Questions?

Diffraction



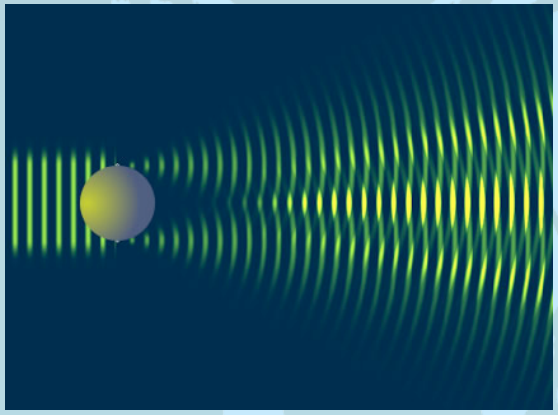
Diffraction

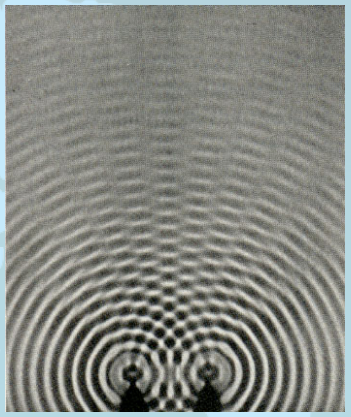
Constructive interference of light waves can produce color separation.

The physical mechanism in this case is called diffraction.

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

Diffraction causes Interference

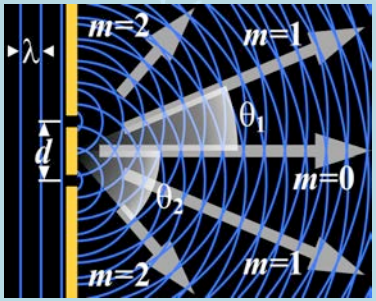




Diffraction: the apparent bending of waves around small obstacles and the spreading out of waves past small openings.

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

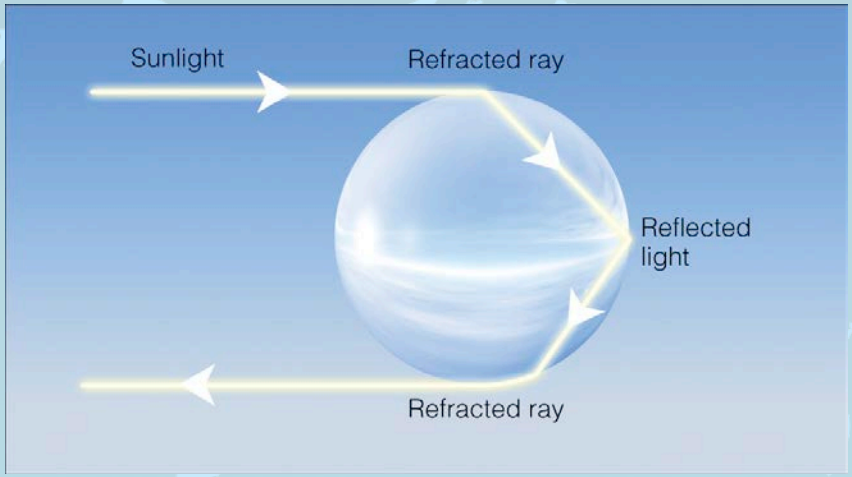
Corona

Diffraction by Cloud Droplets

Corona

Diffraction by Pollen

Diffraction and Reflection



Glory

Diffraction and Reflection

Glory

Diffraction and Reflection

Glory

Diffraction and Reflection

Glory

Diffraction and Reflection

Glory

Diffraction and Reflection

Glory and Fog Bow

Diffraction and Reflection

Supernumerary Bows

Supernumerary Bows

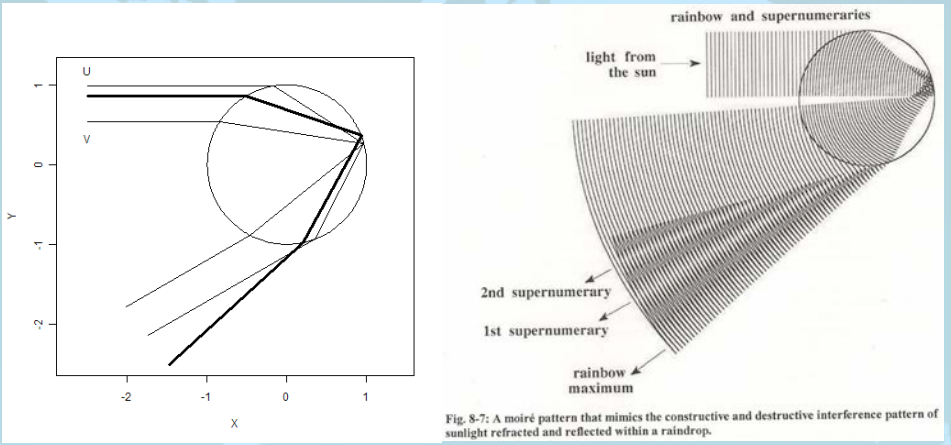


Fig. 8-7: A moiré pattern that mimics the constructive and destructive interference pattern of sunlight refracted and reflected within a raindrop.

The faint bows in the inside of the primary rainbow are caused by interference or diffraction in reflected rays.

Summary: Atmospheric Optics

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

- Scattering
- Reflection
- Refraction
- Diffraction

Observation Assignment 12/5