ATM 10 Severe and Unusual Weather

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http://atm.ucdavis.edu/~grotjahn/course/atm10/index.html

Lecture topics:

- **Optics: Scattering**
  - Sky Colors and Rays
- **Optics: refraction**
  - Mirages and Refraction
  - Rainbows
  - Sun Dogs and Halos
- **Optics: diffraction & reflection**
  - coronas
  - halos

Scattering – Sky Colors and Rays

- Optical phenomena caused by SCATTERING

Why is the sky **Blue?**
Why are clouds **White?**

Figure 1.3

Nitrogen, oxygen, argon, water vapor, carbon dioxide, and most other gases are colorless. – BUT, they cause light to scatter.

Clouds are composed of cloud droplets that do not have color either but are translucent

Scattering is a deflection of light due to reflection into different directions. For example: a cloud

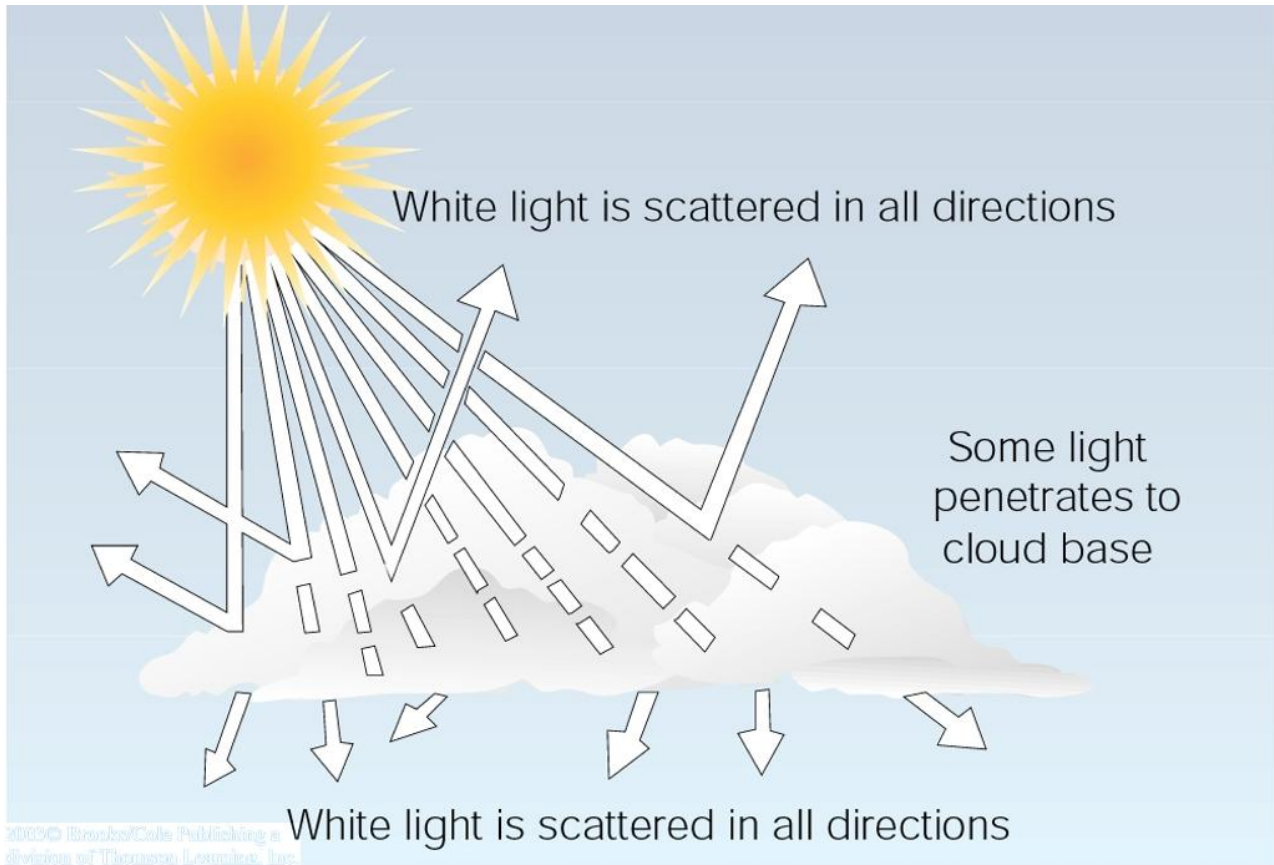


Figure 4.2

Rayleigh Scattering makes Blue Skies

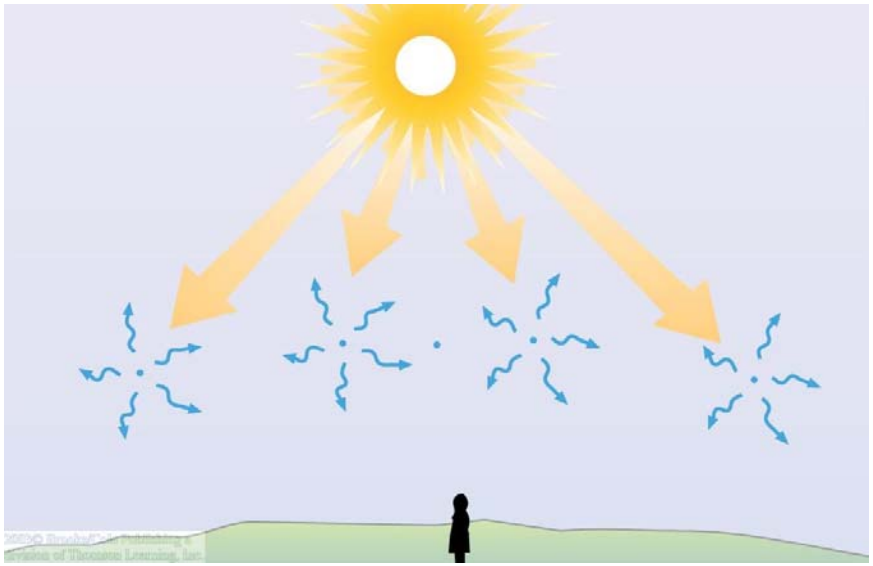


Figure 4.4

Zion NP. © R. Grotjahn

Air molecules are only large enough to reflect the smallest wavelength light, which is blue.

Rayleigh scattering takes a beam of sunlight and selectively creates blue skies.

A yellow sun is evidence of this removed blue light.

Dark Blue above – white near horizon

- Whiter near horizon because light from that direction has come many different distances through atmosphere.
  - Encounters more dust
  - Encounters more air
- Longer paths scatter reds too.

Colorado. © R. Grotjahn

Colorful Sun & Clouds

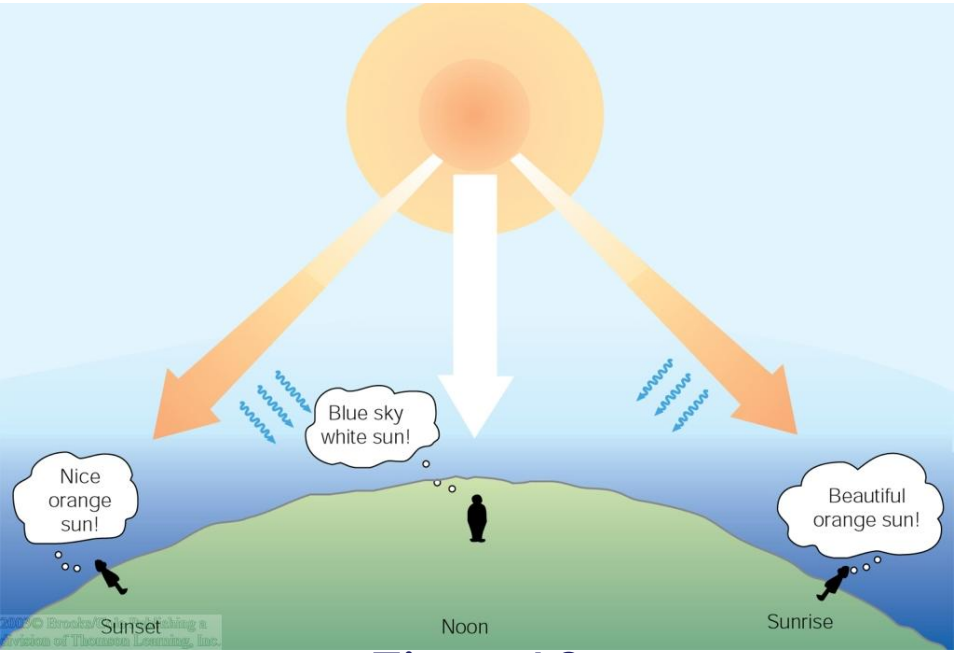
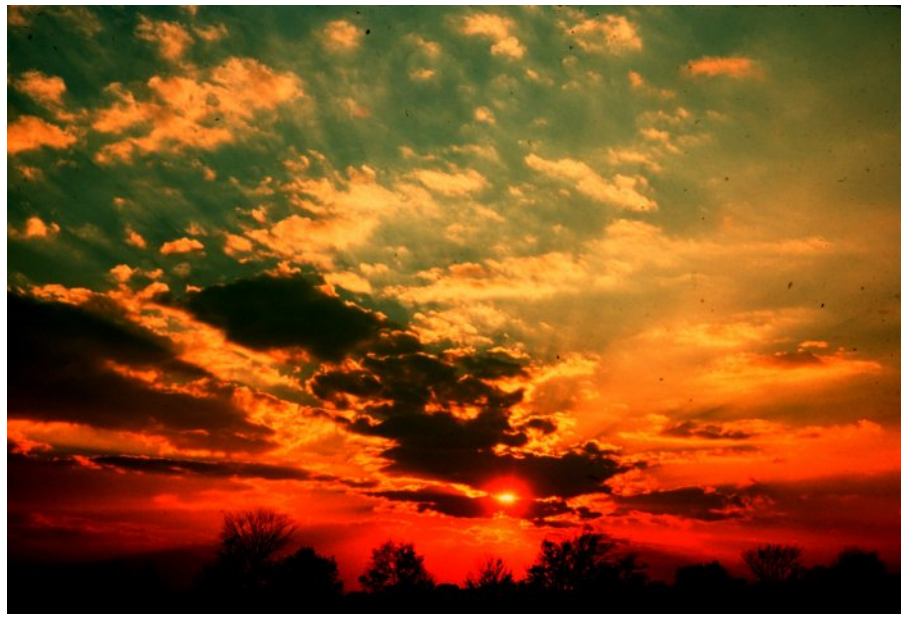


Figure 4.8



Low on the horizon, the sun's light passes through nearly 12 times more atmospheric gas and aerosol, which scatters most short wavelengths.

Longer oranges and reds then comprise the sunlight, which reflects from clouds and water.

Arches NP. © R. Grotjahn

Geometric Scattering - White & Dark Clouds

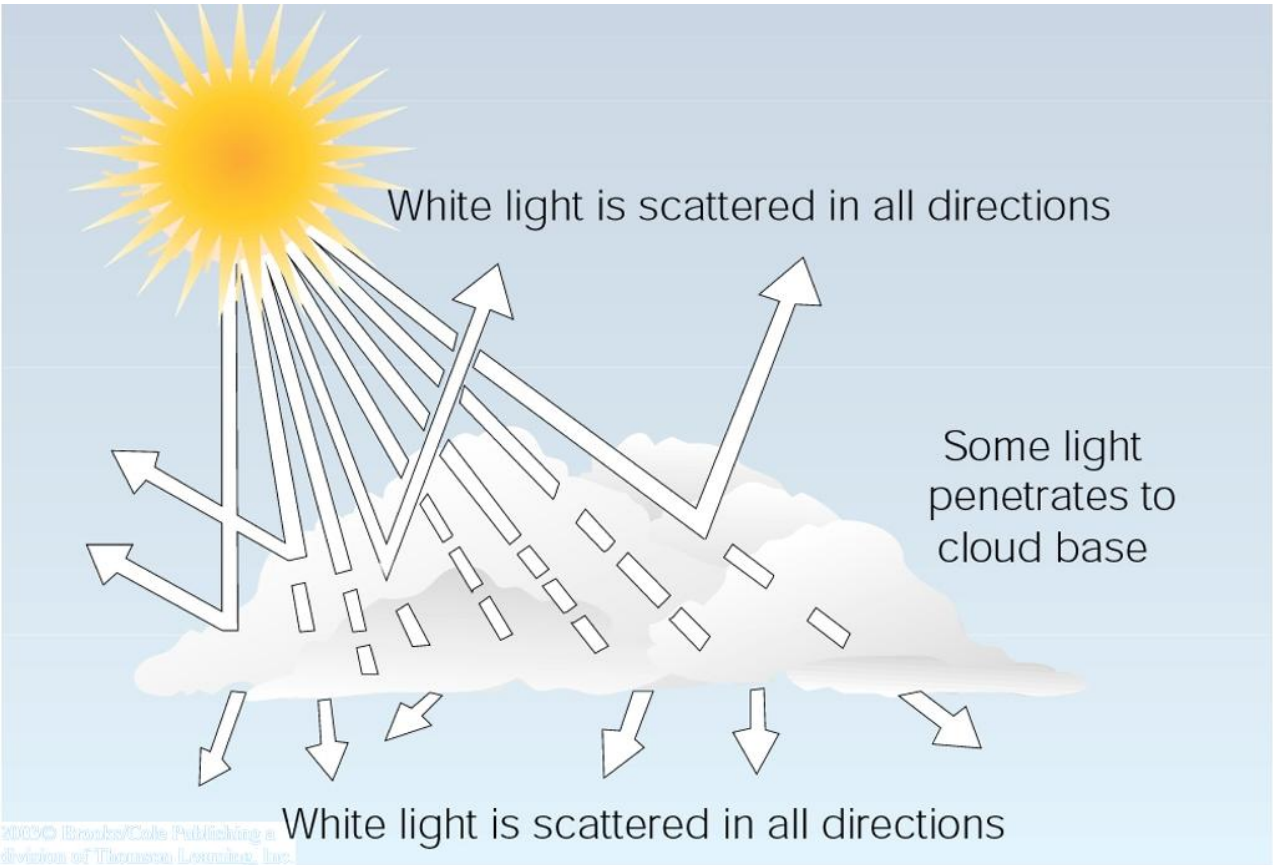


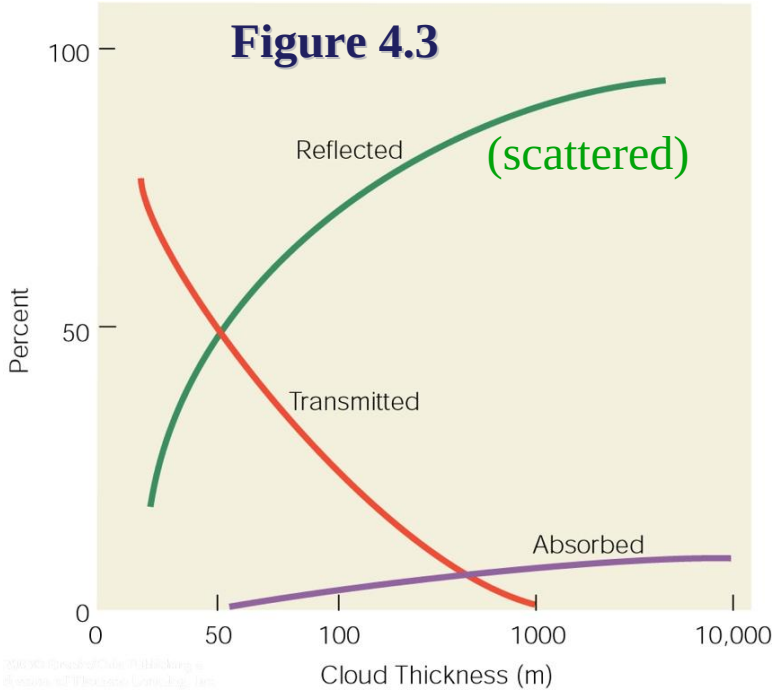
Figure 4.2

Cloud water droplets are poor absorbers of light, but large enough to reflect all wavelengths as geometric scatterers.

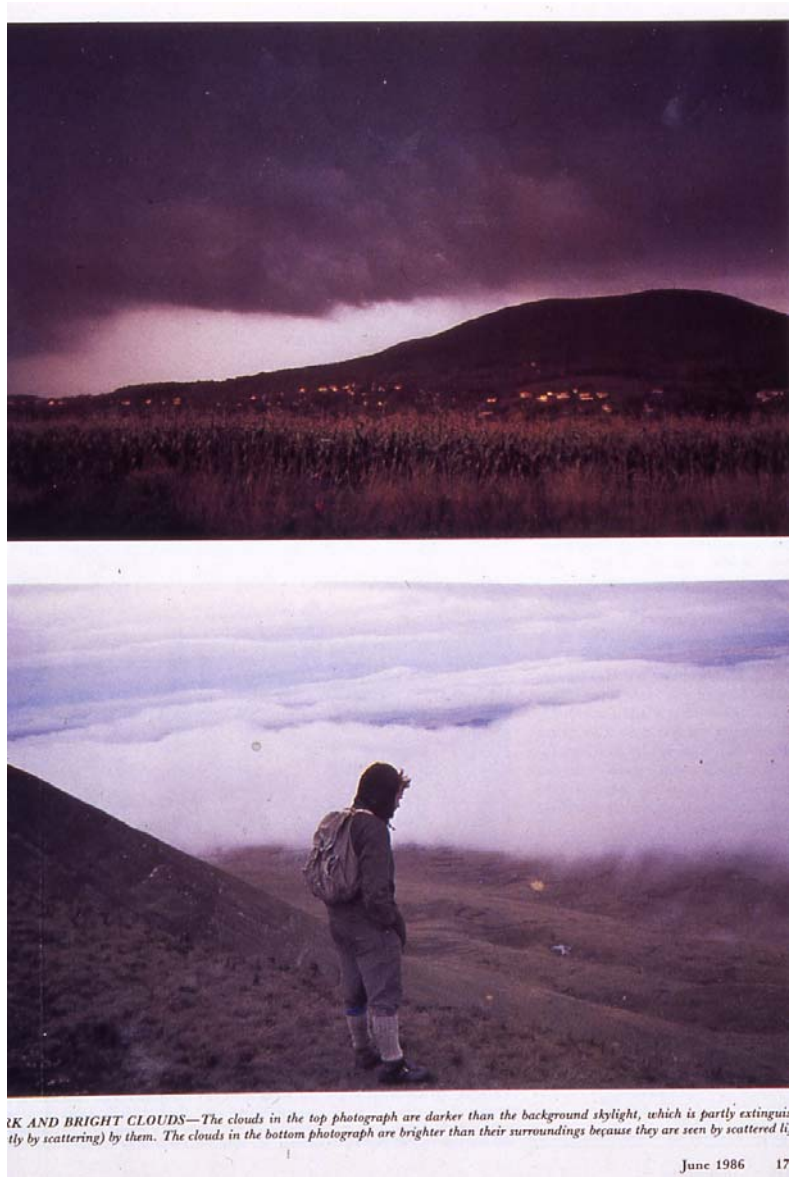
By scattering all visible wavelengths equally, the cloud does not change the color of the light.

Thick clouds, however, diminish the passage of light, and appear dark.

Reflected, Transmitted, & Absorbed



As a wave of light passes through a cloud, only a small amount is absorbed, and the rest is either reflected or transmitted as a function of cloud thickness.



Other large particles

Tasmania. © R. Grotjahn

Raindrops

Death Valley. © R. Grotjahn

Large dust particles

Mie scattering - Smog

Looking towards sun - bright

Looking away from sun - dark

Ground based smog is visible because those reactants of nitrogen and ozone scatter & absorb light different than clean air

These particles are smaller than droplets, but much bigger than molecules: Mie scattering

Boulder CO. photos © R. Grotjahn

Geometric Scattering - Crepuscular Rays

Figure 4.7

Grand Tetons. © R. Grotjahn

Dust and salts are large enough to cause geometric scattering, and change blue skies into hazy white skies.

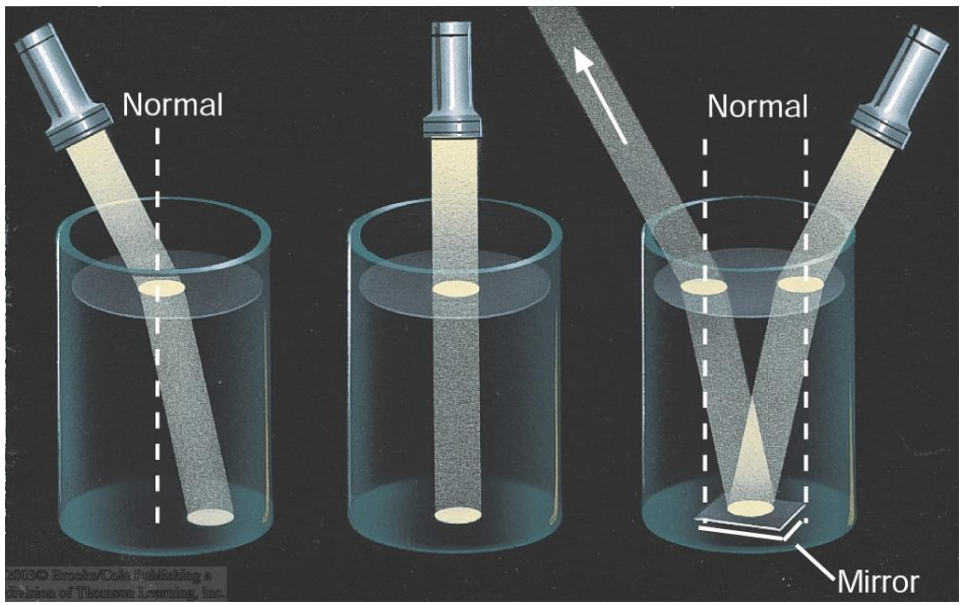
Concentrated dust or salts beneath clouds can create white crepuscular rays of sunlight.

Refraction – Mirages, Rainbows, Sundogs and Halos

Refraction – 2 principles

1. **Refraction** occurs when light encounters a substance of different density at an angle.
2. A refracted beam bends **towards the denser** substance. (Towards cooler air)

Recall ideal gas law: $P = \rho R T$



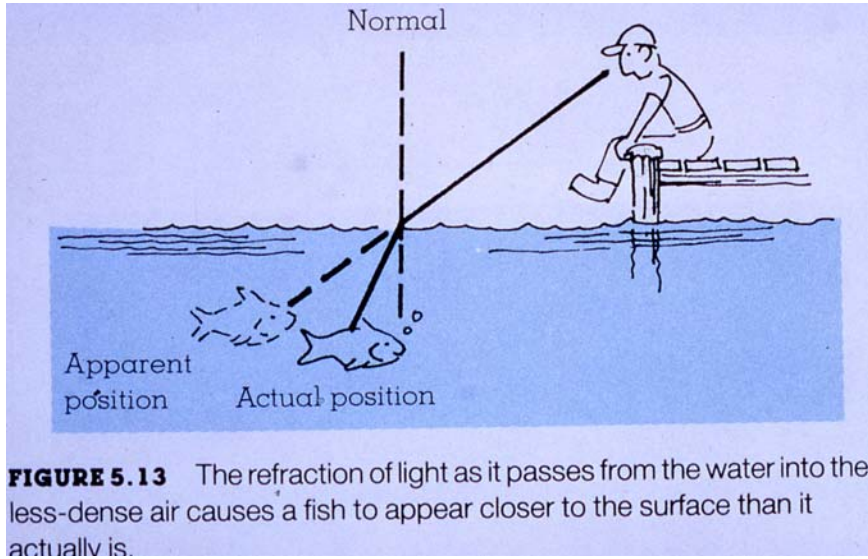


FIGURE 5.13 The refraction of light as it passes from the water into the less-dense air causes a fish to appear closer to the surface than it actually is.

Refraction - Inferior mirages

- Two underlying principles
  1. Light passing through air of different densities is refracted
  2. Light is bent towards cooler air

- Recall ideal gas law: $P = \rho R T$

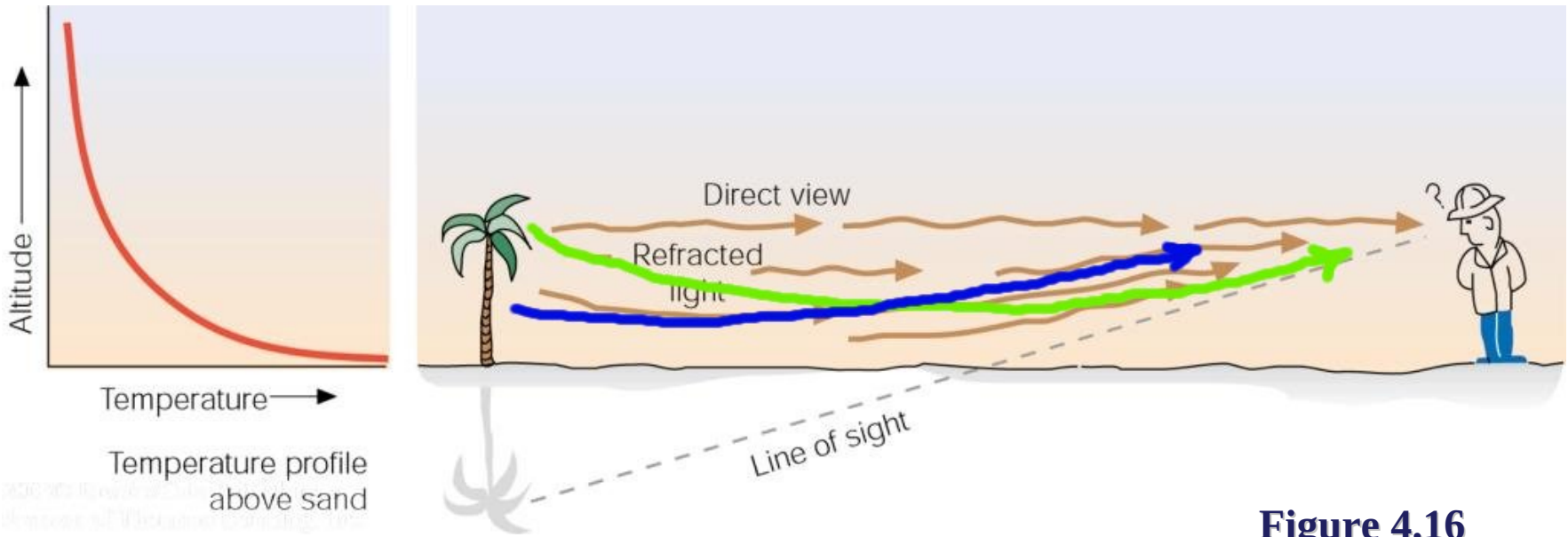


Figure 4.16

Refraction - Superior Mirage

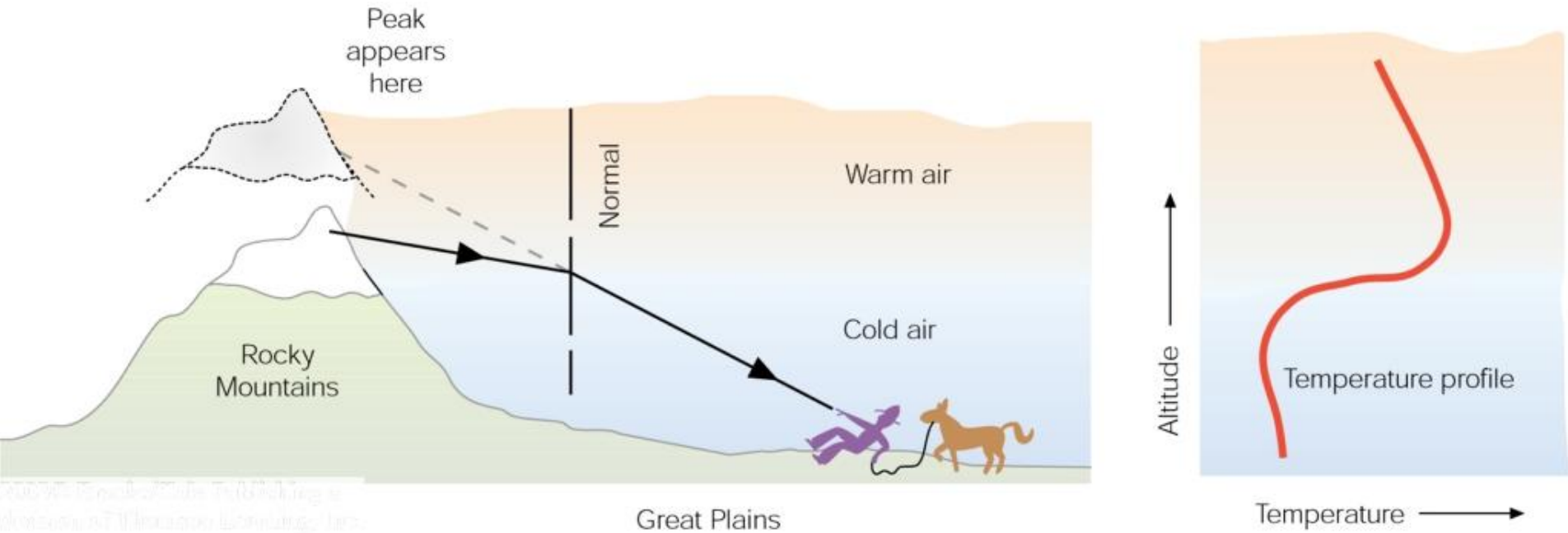


Figure 4.17

A superior mirage occurs when warm air rests above cold air, causing the line of sight to head upward and the object appear at a higher altitude.

(polar regions) – Superior mirage

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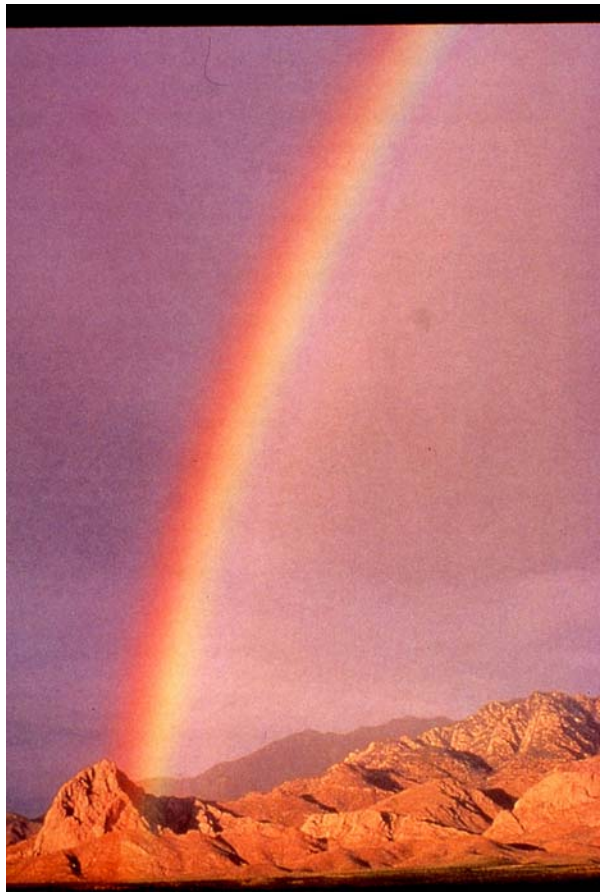
Plate 7-7. Another variation of the fata morgana mirage over the Arctic

Refraction – Rainbows

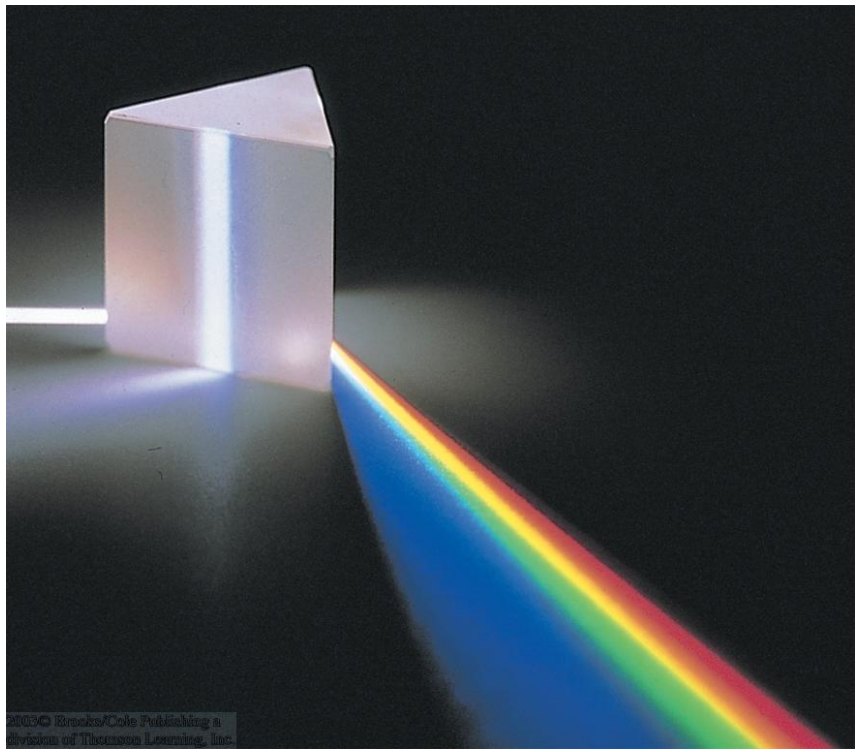
- Red on the outside,
- Blue on the inside
- Is that all?



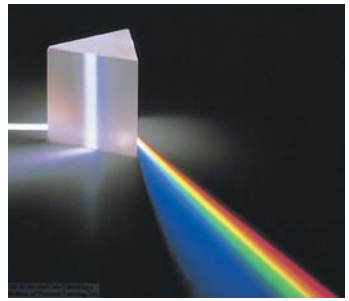
Capitol Reef NP. © R. Grotjahn

Rainbow Colors - Prism

- White light is composed of many colors.
- When white light passes through something of different density it refracts.
- Different colors refract different amounts.
- Red refracted less than blue



Primary Reflection & Refraction



Angle incidence = angle of reflection

Figure 4.27a

Refraction when go from air to water

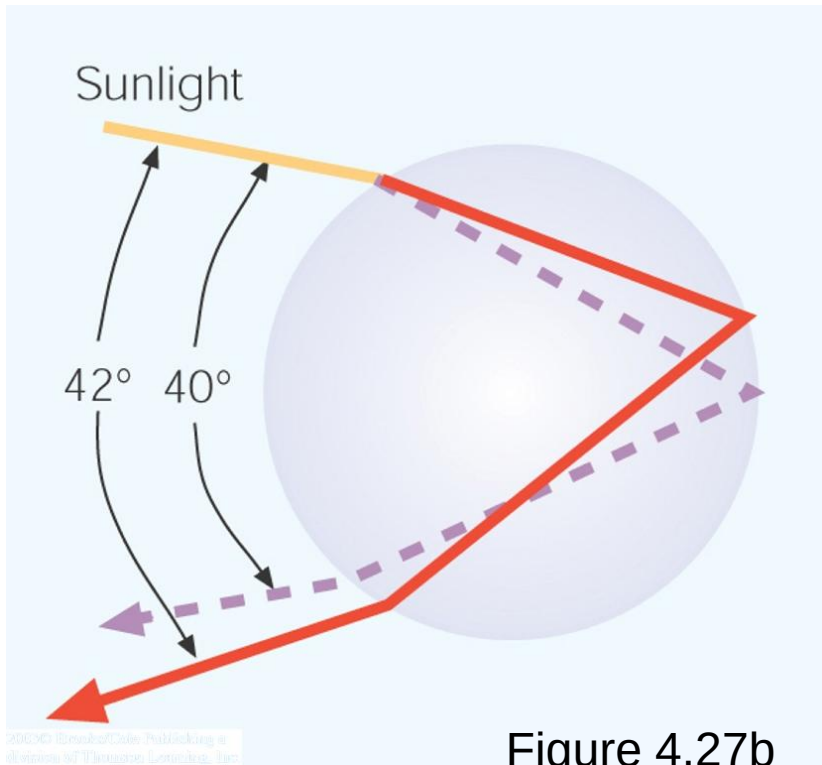


Figure 4.27b

Primary Rainbow

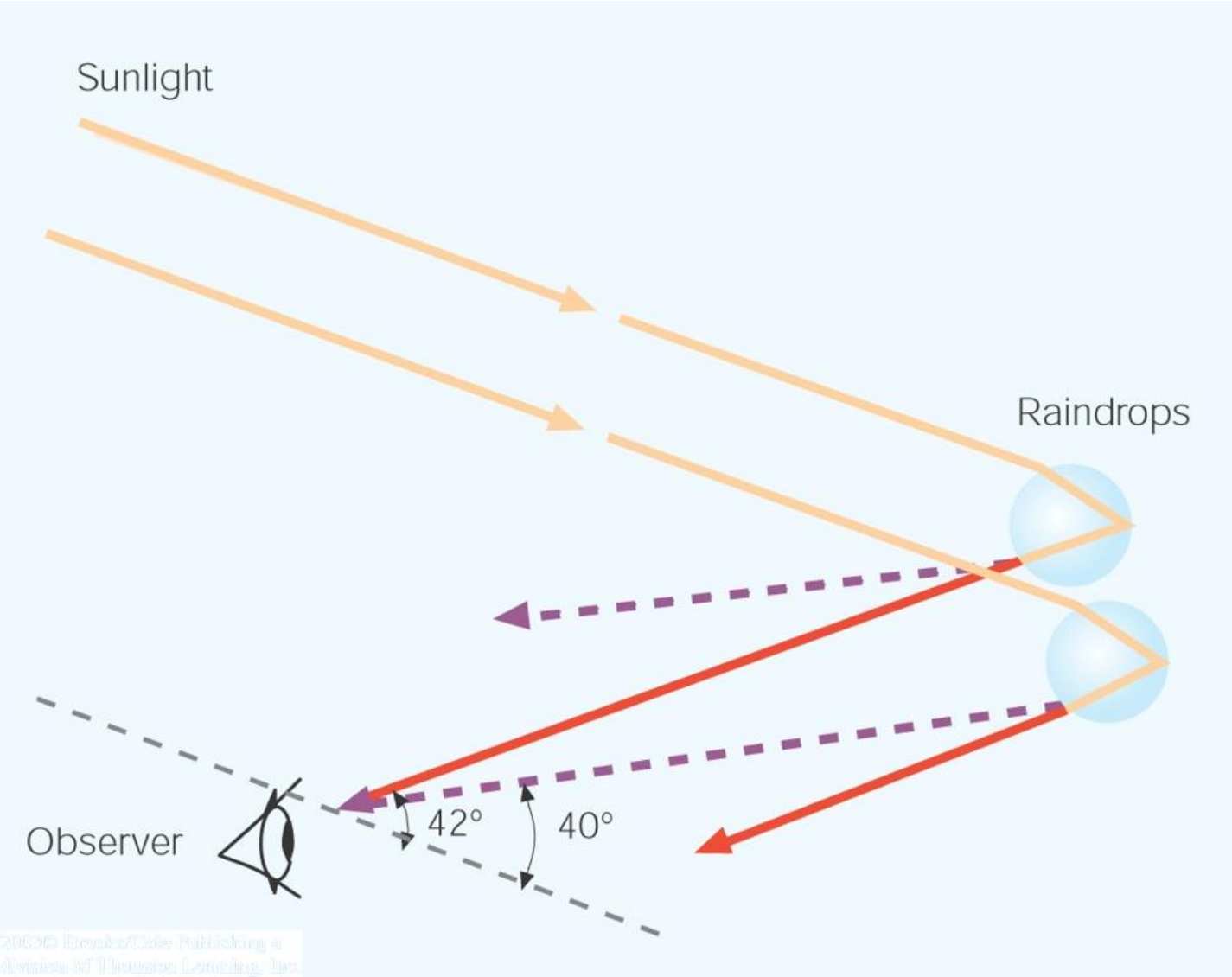


Figure 4.28

Red bends least, and leaves the raindrop below the blue and violet colors.

An observer, however, sees a rainbow by capturing one color per drop, where red and its small bend is now required to reside at the rainbow top.

Rainbows & Rainfall

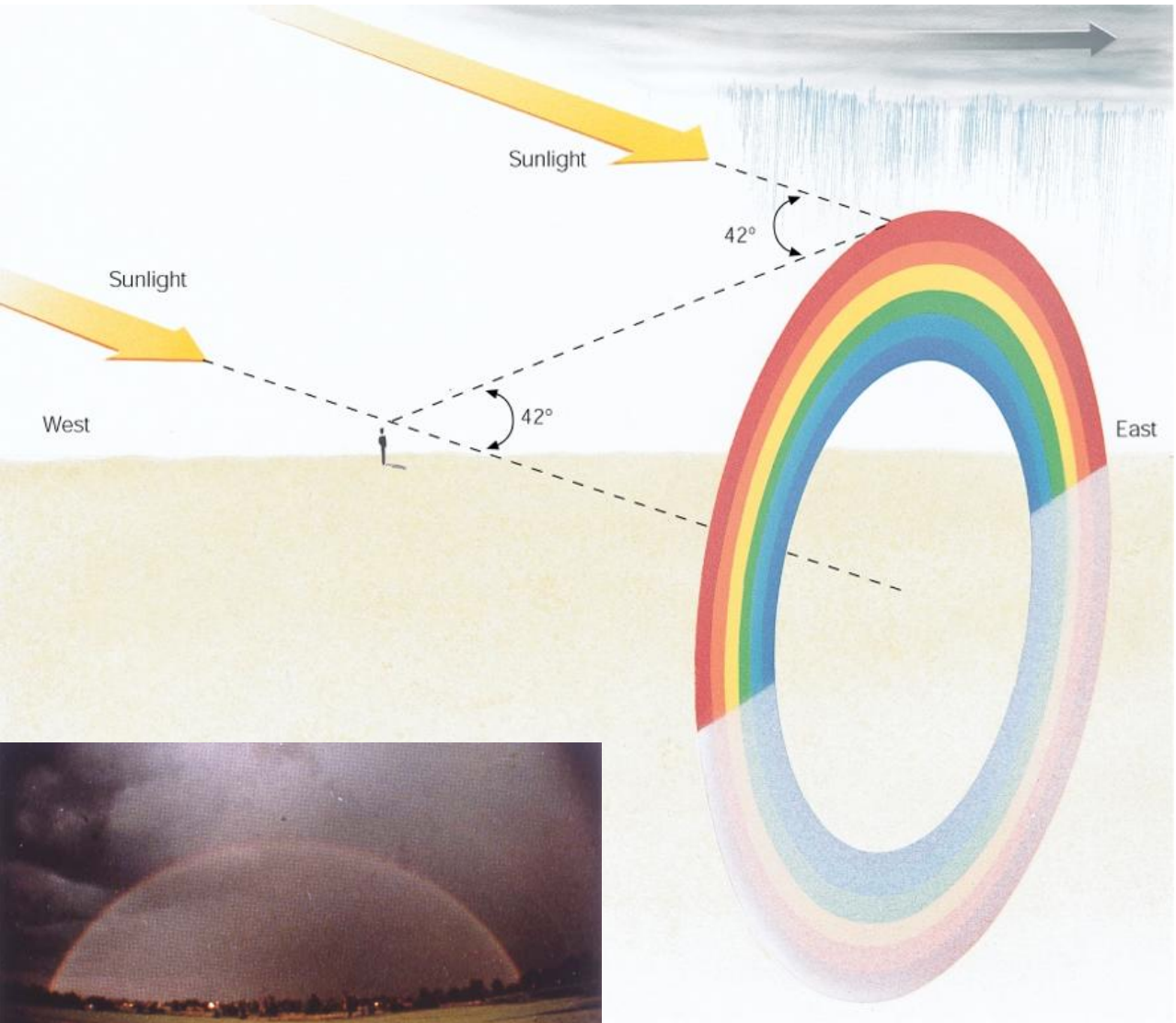


Figure 4.26

Rainbows, and red skies, have been used to foretell the weather.

Rainbows are only seen when the viewer has their back to the sun and raindrops before them.

Because weather is predominantly from the west, a rainbow at sunset means the storm has already passed.

Double Reflection for Secondary Bow

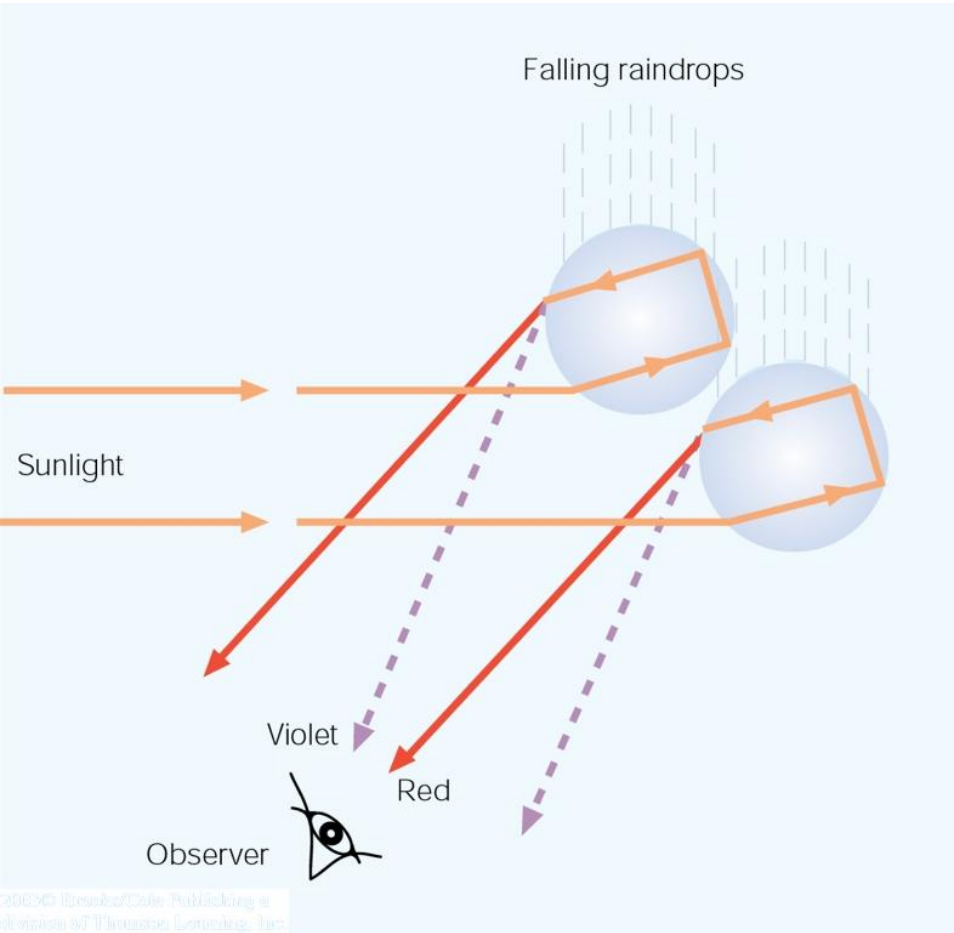


Figure 4.30

Figure 4.29

Sunlight entering a raindrop may reflect twice before exiting, which reverses the color sequence and diminishes the rainbow intensity.

A few more things…

Navajo Pk Colorado © R. Grotjahn

Dark band between Primary and Secondary rainbows

Boulder Colorado. © R. Grotjahn

Supernumerary arcs

Delta Utah. © R. Grotjahn

Refraction – Sun Dogs and Halos

Sundogs in ice crystals blowing in air near the ground (note hillside)

Sundog in high elevation ice cloud

Refraction - Sun Dogs

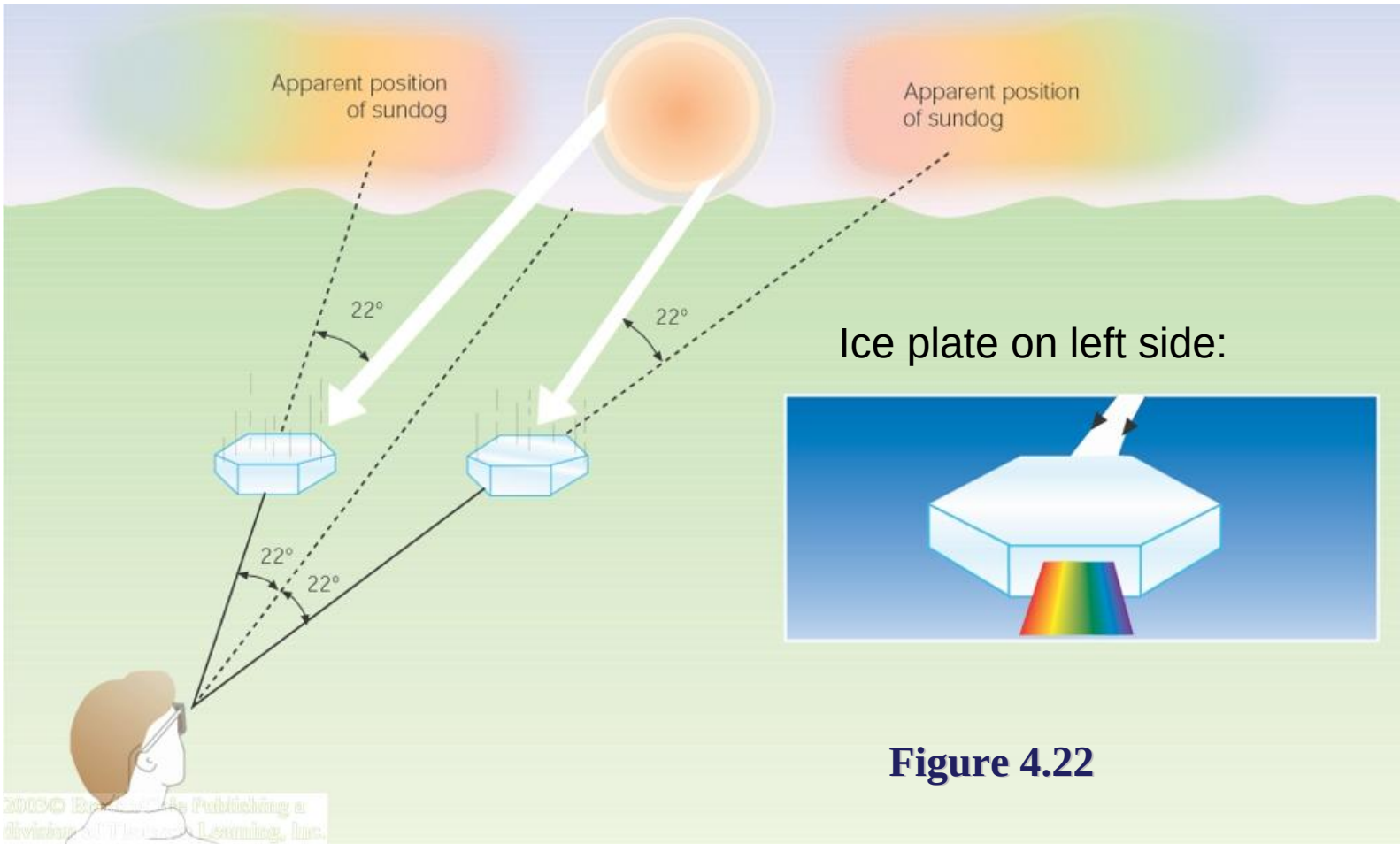


Figure 4.22

- Ice crystals selectively refract (bend) sunlight like a prism.
- The angle change is again greater for blue than for red.
- Hexagonal plates fall like feathers, flat side up.

Ice Crystal Halo

Figure 4.18

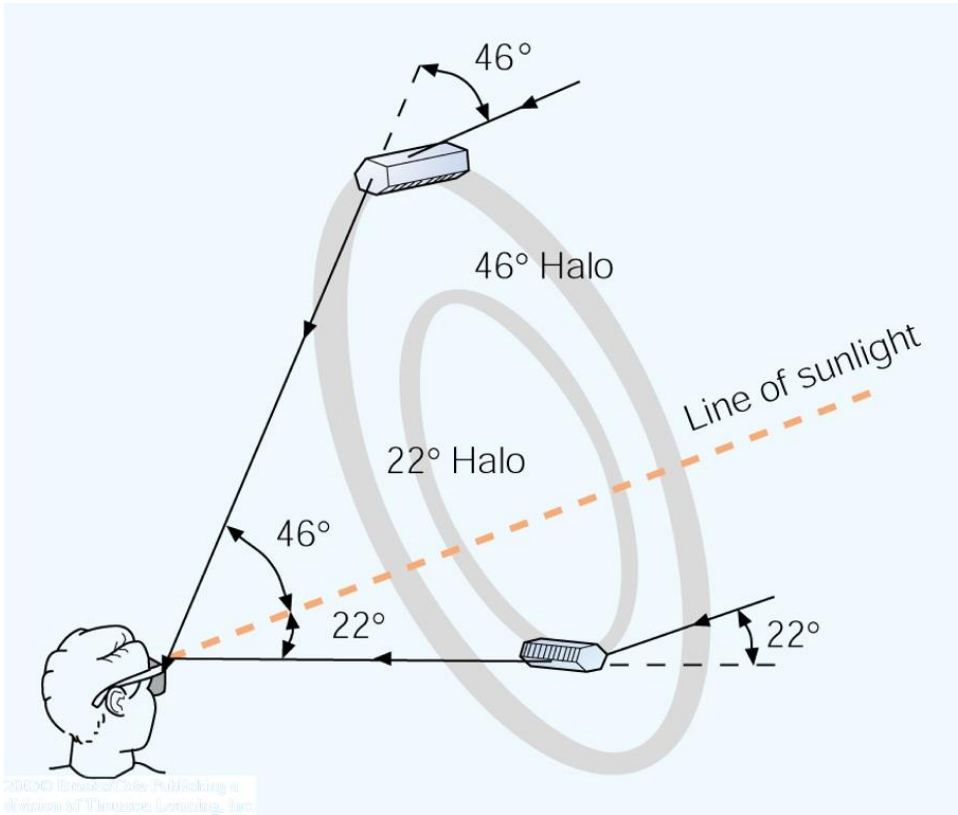


Figure 4.19

Cirriform cloud ice crystals randomly oriented to the ground refract light at an angle of 22° to create an arc.

Less common are the 46° halo, which require more regular column-type crystals.

Reflection & Sun Pillar

Figure 4.24

Sun pillars are formed by reflection of light off, not refraction of light through, ice crystals falling in still air.

Halo Tangent Arc

Figure 4.20

An arc of light forms tangent to the halo when large hexagonal crystals fall with their long axis horizontal to the ground.

So, just what is this?

← Here's a hint!

Summary of Ice Crystal Phenomena

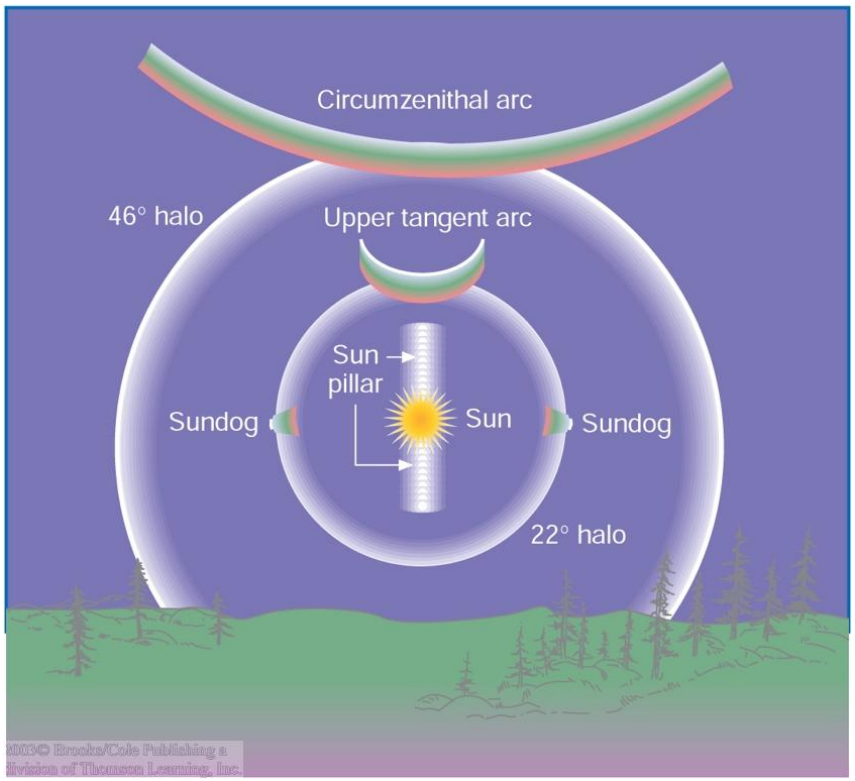


Figure 4.25

Can you see:
The 22 degree halo,
The sundogs,
The sun pillar, AND
The upper tangent arc?

Diffraction – Coronas and Glories

Diffraction – Defined

- Mainly due to diffraction of light.
- What is Diffraction?
  - Bending of light around an obstacle
  - The obstacles are small ice particles or liquid water droplets
- Diffraction is like the waves bending at the point of a beach.

Morro Bay, CA

Diffraction - Coronas

Figure 4.31

Figure 4.32

Solar and lunar coronas are caused by diffraction, or bending of light as it passes around (not through) ice crystals or pollutants.

Diffraction causes circles of increased illumination where a wave of light reinforces other waves of light.

Diffraction & Colors

Bending white light by non-uniform cloud droplets causes distorted separation of the different wavelengths, as seen in this colorful cloud based corona.

Diffraction and Refraction - Glories

Figure 4.34

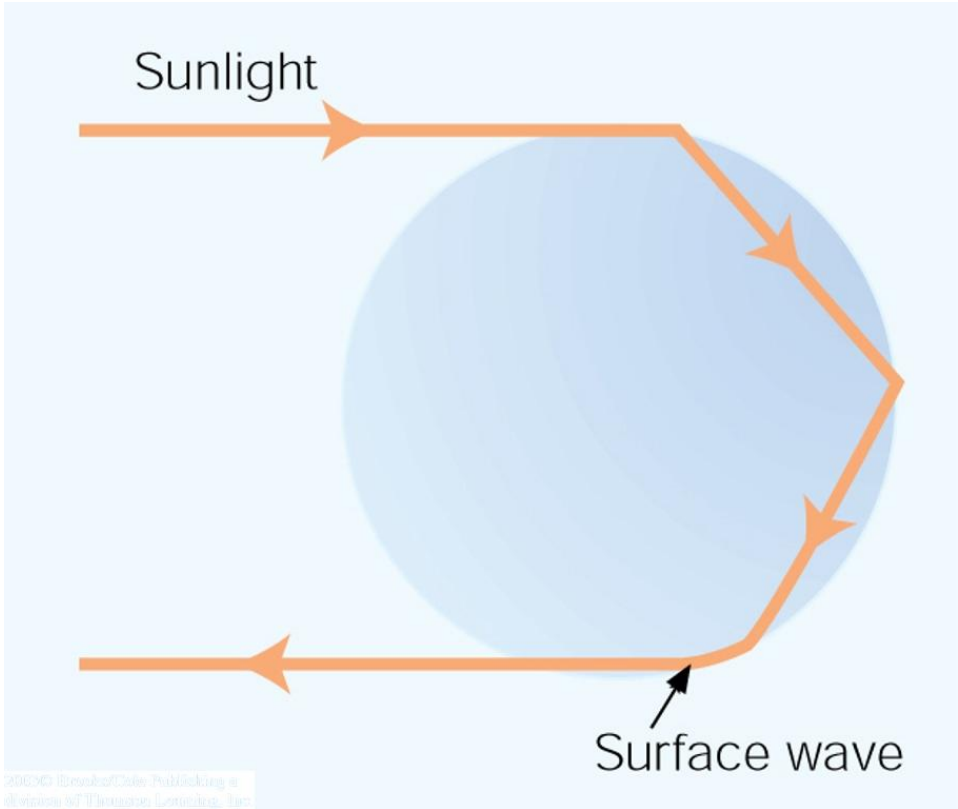


Figure 4.35

The glory around the aircraft shadow is attributed to diffraction, but based partly on surface refraction to create the bending that brings the light back to the viewer.

End of lecture 3