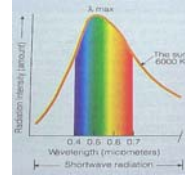


Atmospheric Optics

AT350

Colors and Brightness

- ~50% of the sun's energy enters our atmosphere as visible light
- Visible light in the atmosphere can be
 - Reflected, refracted, scattered
 - Absorbed
 - Transmitted
- What we see, and what it looks like, depends on these phenomena



- Light waves stimulate nerve endings in the retina
- Rods respond to all visible wavelengths and "measure" brightness
- Cones respond to specific wavelengths between 0.4 and 0.7 μm
 - Without cones, our vision would be B&W
 - Defective or missing cones cause color blindness

Object Color

- White corresponds to similar amounts of all visible wavelengths striking eye cones
- Objects that emit visible light can appear colored if some wavelengths are emitted more strongly
 - Spectrum depends on object T
- Cooler objects can appear colored if they absorb selected visible wavelengths
 - e.g., a red object is absorbing all wavelengths except those in the red range



Light Scattering

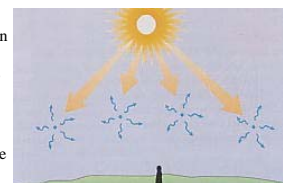
- Light can be thought of as a set of electromagnetic waves.
- Light is scattered when these waves interact with other objects. The nature of the scattering depends on the object properties, especially the size of the object
- Three scattering types
 - Rayleigh scattering: the object is much smaller than the wavelength of light (~0.4-0.7 μm)
 - scattering proportional to $1/\lambda^4$
 - Shorter (violet, blue) wavelengths scattered more efficiently

Light Scattering (cont'd)

- Mie Scattering: The object is similar in size to the wavelength of light
 - Most efficient scattering (light scattered from a cross-section up to several times the object cross-section)
 - Calculation of light scattering amount complex (Maxwell's Equations)
 - Many air pollution particles are in this size range
- Geometric Scattering: The object is much larger than the light wavelength
 - Cloud drops are geometric scatterers
 - Visible wavelengths scattered with similar efficiency
 - Object scatters a cross-section of incoming light equal to twice its own cross-section
 - Consider the Extinction Paradox

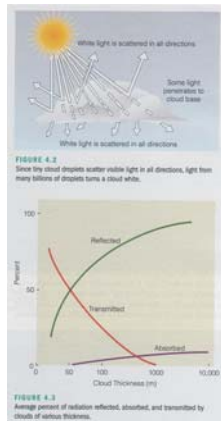
Why is the day sky blue?

- Sunlight is scattered by air molecules
- Air molecules are much smaller than the light's λ
- Rayleigh scattering (proportional to $1/\lambda^4$) occurs
- Shorter wavelengths (green, blue, violet) scattered more efficiently
- Unless we are looking directly at the sun, we are viewing light scattered by the atmosphere, so the color we see is dominated by short visible wavelengths
 - blue dominates over violet because our eyes are more sensitive to blue light



What makes clouds white/grey/black?

- Cloud drops are ~ 5-50 μm
 - Geometric scatterers
 - All visible λ 's scattered with similar efficiency
- When clouds are viewed from above they appear bright white
 - Backscattered sunlight
- When viewed from below, clouds can appear white, grey or black
 - Transmitted and forward-scattered light make thin clouds appear white
 - Thicker clouds
 - Scatter and absorb more light
 - Can appear dark/black
 - Large drops are better absorbers

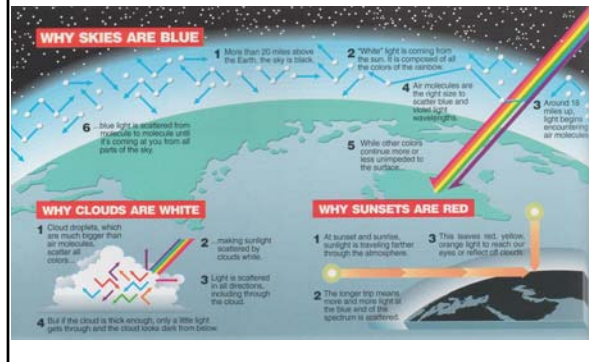


Why are sunsets red?

- The sun appears fairly white when it's high in the sky
- Near the horizon, sunlight must penetrate a much greater atmospheric path
 - More scattering
- In a clean atmosphere, scattering by gases removes short visible λ 's from the line-of-sight
 - Sun appears orange/yellow because only longer wavelengths make it through
- When particle concentrations are high, the slightly longer yellow λ 's are also scattered
 - Mie scattering
 - Sun appears red/orange



Blue sky summary



Other Atmospheric Scattering Examples



Refraction

- The speed of light changes as the light enters regions of different density
 - Speed slows/rises as density rises/falls
 - If entrance to the new range is made at an angle, the light bends (refraction)
 - Toward/away from the normal for increasing/decreasing density

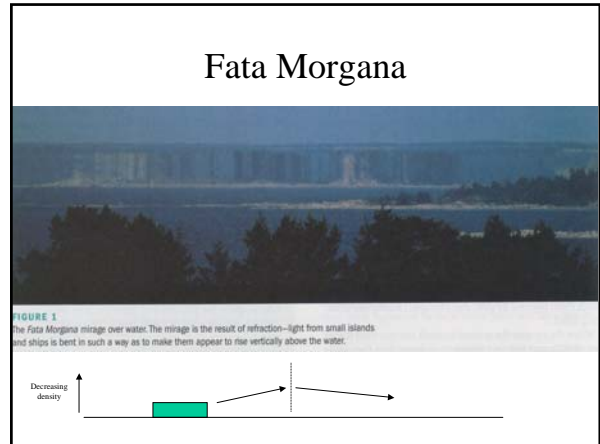
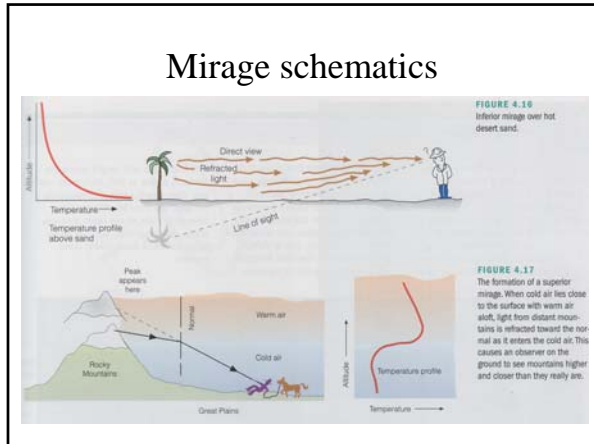


- Atmospheric refraction changes the apparent position of light sources (objects)
- How does this affect
 - Time of sunset ?
 - Twilight ?

What are mirages?

- A mirage occurs when an object appears displaced from its true position
 - Mirages are not mind tricks
 - They are caused by light refraction associated with atmospheric density gradients





Coronas and halos

Coronas, halos and streaks of light
Light from the sun and moon passing through clouds can create many colorful halos, coronas, or streaks of light. These are some of the most common kinds.

The corona
A corona is a series of concentric circles of light seen when the sun or moon is shining through clouds. Since the sun can blind you, it's easier to see a corona around the moon. It may look colorful, but it's not a spectrum. It's caused by the moon and a rainbow from around the outside. Coronas are caused by the light bending—total reflection—of light passing through clouds.

Halo and arcs
Unlike a corona, halos don't touch the sun or moon. They're circles of light, caused by the bending—refraction—of light rays as they pass through ice crystals. Different shapes of crystals pointing in different directions account for the wide range of shapes you see including halos, arcs and various kinds of spectacles of light.

Sun dogs and pillars

How ice crystals create 'sun dogs'
One of the most common ice crystal displays is what appears to be copies of the sun on either side, often both sides, of the sun when it's low in the sky. These are known as sun dogs, mock suns or parhelia. They're from ice crystals create them.

1. Clouds are made of ice and the crystals with the sun.
2. Light entering a crystal is bent at a 22-degree angle.
3. And the refracted light creates the sun dogs on either side of the real sun.

Sun pillars
Light reflecting off small ice crystals creates sun pillars, which can be above or below the sun.

Diamond dust
On very cold nights when small ice crystals—sometimes called diamond dust—are in the air, reflections of almost lights off the ice can create full spectra of light.

Ice crystal optics summary

FIGURE 4.24
A sun pillar produced by the reflection of sunlight off ice crystals.

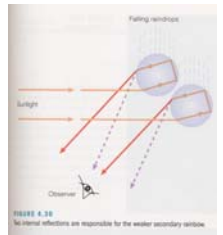
FIGURE 4.25
Ice crystal phenomena. (A picture of the circumzenithal arc is in Fig. 2 on p. 98.)

Rainbows

- Internal reflection of sunlight by raindrops
 - Light entering denser drop slows and bends
 - Short wavelengths refract the most
 - Most light passes through drop, but some strikes backside at **critical angle** (~42 degrees, depending on λ) and is reflected
- Light refraction experiment by Newton in 17th century provided first scientific explanation
- Occurs when sun is at our back
- Rainbow most likely when sun is close to the horizon
- Rainbow would form full circle if horizon were absent
- Different colors seen in rainbow come from drops at different heights
- Double rainbows possible when two internal reflections occur
 - Second rainbow weaker because it comes from two reflections
- Moonbows and fogbows also possible

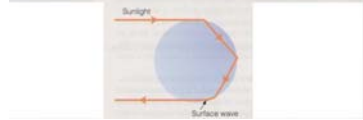
Rainbow schematics

- Rainbow in morning, sailors take warning
Rainbow at night, a sailor's delight



The glory

- Aircraft above cloud layer
- Drops $< 50 \mu\text{m}$
- Refraction, internal reflection and surface skimming
- Slightly different departure angles for different λ 's produce colored rings



Questions for thought

- Why are star colors related to star temperatures while planet colors are not related to planet temperatures?
- How long does twilight last on the moon?
- What would the sky color be if air molecules scattered long λ 's more efficiently?
- Why does smoke arising from a cigarette often have a blue cast yet appear white when blown from the mouth?
- Why are stars more visible with no moon out?