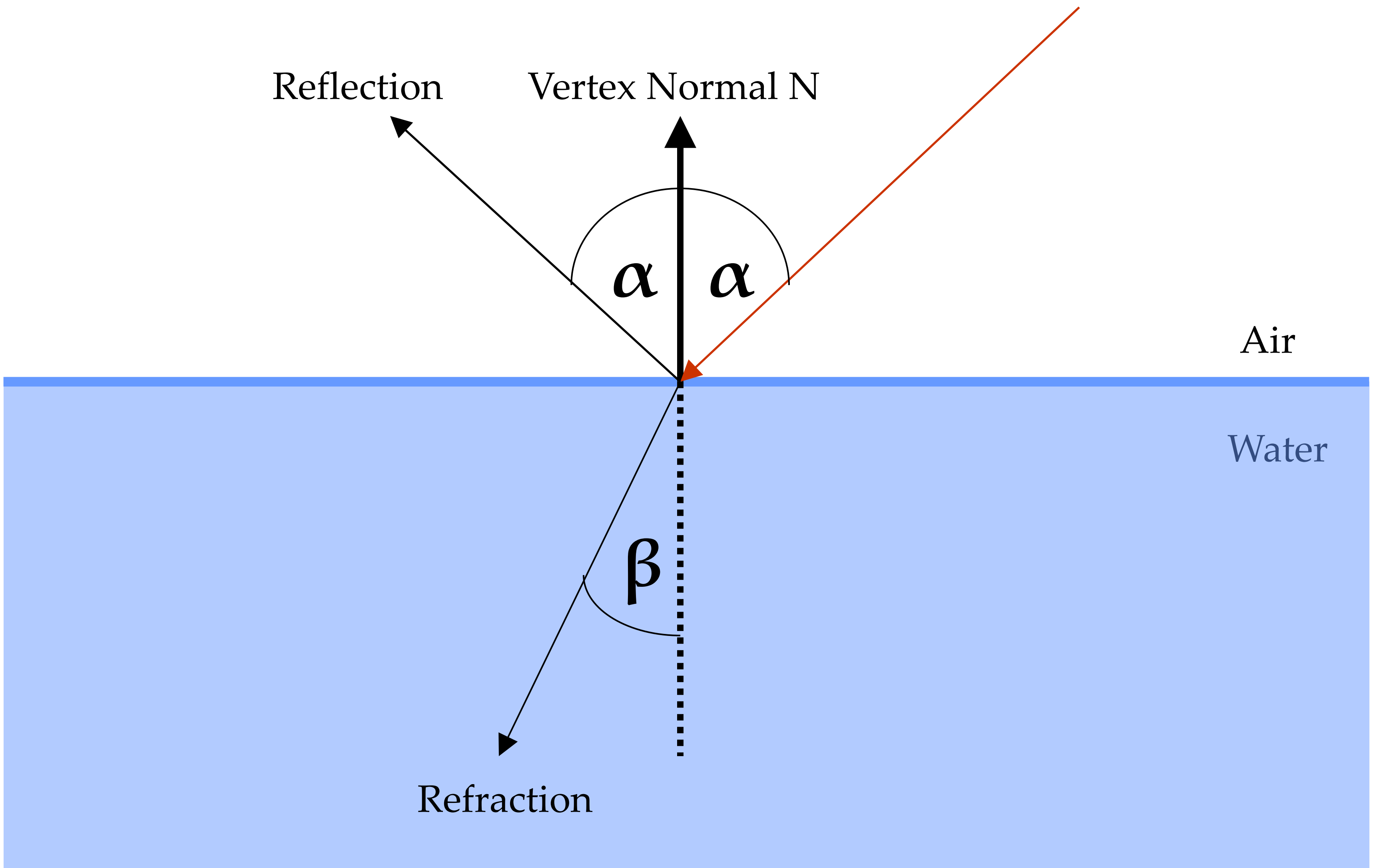
Refractions, Reflections and Caustics : Basic Concepts

Lecture #15

Thanks to Henrik Jensen, John Hart, Ron Fedkiw, Pat Hanrahan, Rahul Swaminathan, Ko Nishino

Reflection and Refraction



Snell's Law

- α Incoming = α Reflected
- $\sin(\alpha)/\sin(\beta)$ = Refractive Index (material dependent)
- Refractive index inversely proportional to speed of light (Huygens Principle)

Air	1.0003
Water	1.333
Glycerin	1.473
Immersion Oil	1.515
Glass (Crown)	1.520
Glass (Flint)	1.656
Zircon	1.920
Diamond	2.417
Lead Sulfide	3.910

Snell's Law and Refractive Index Effects

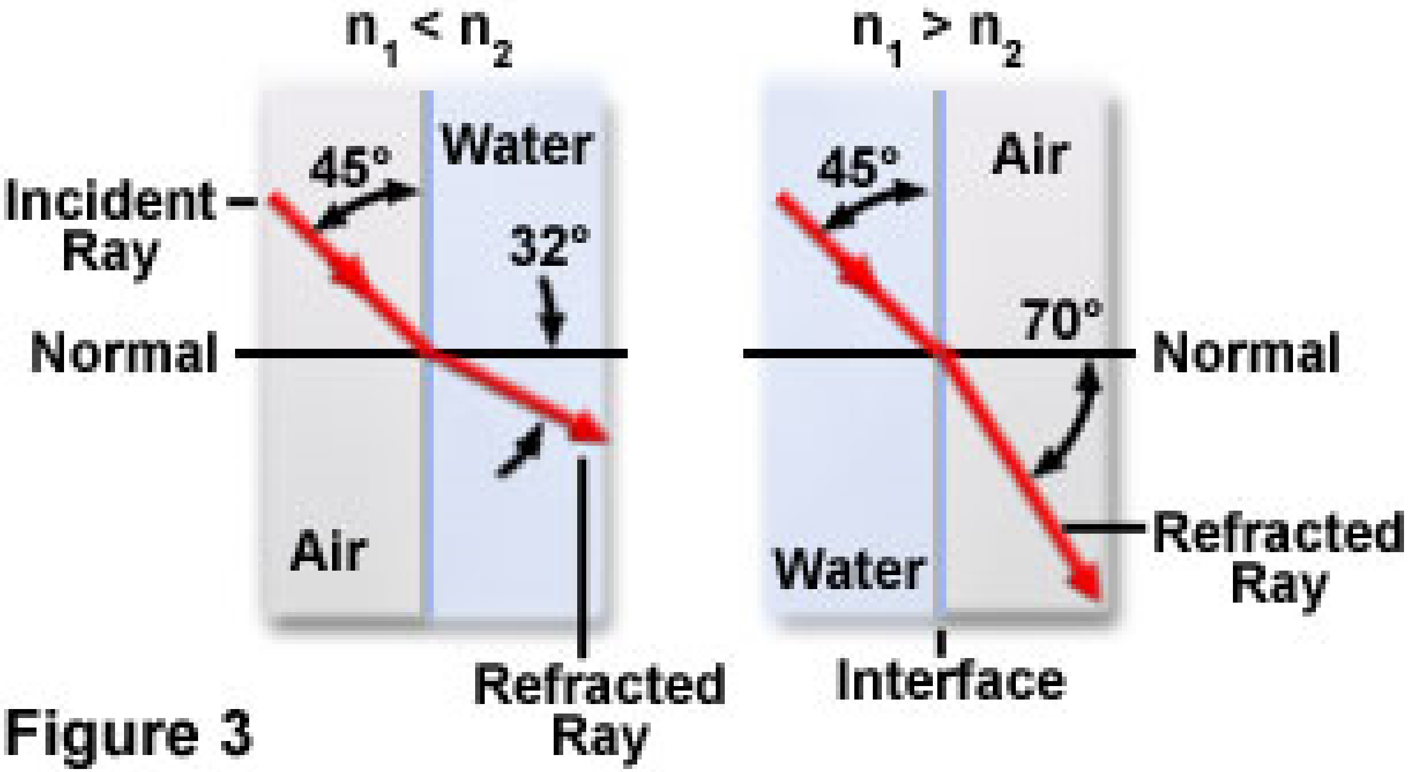
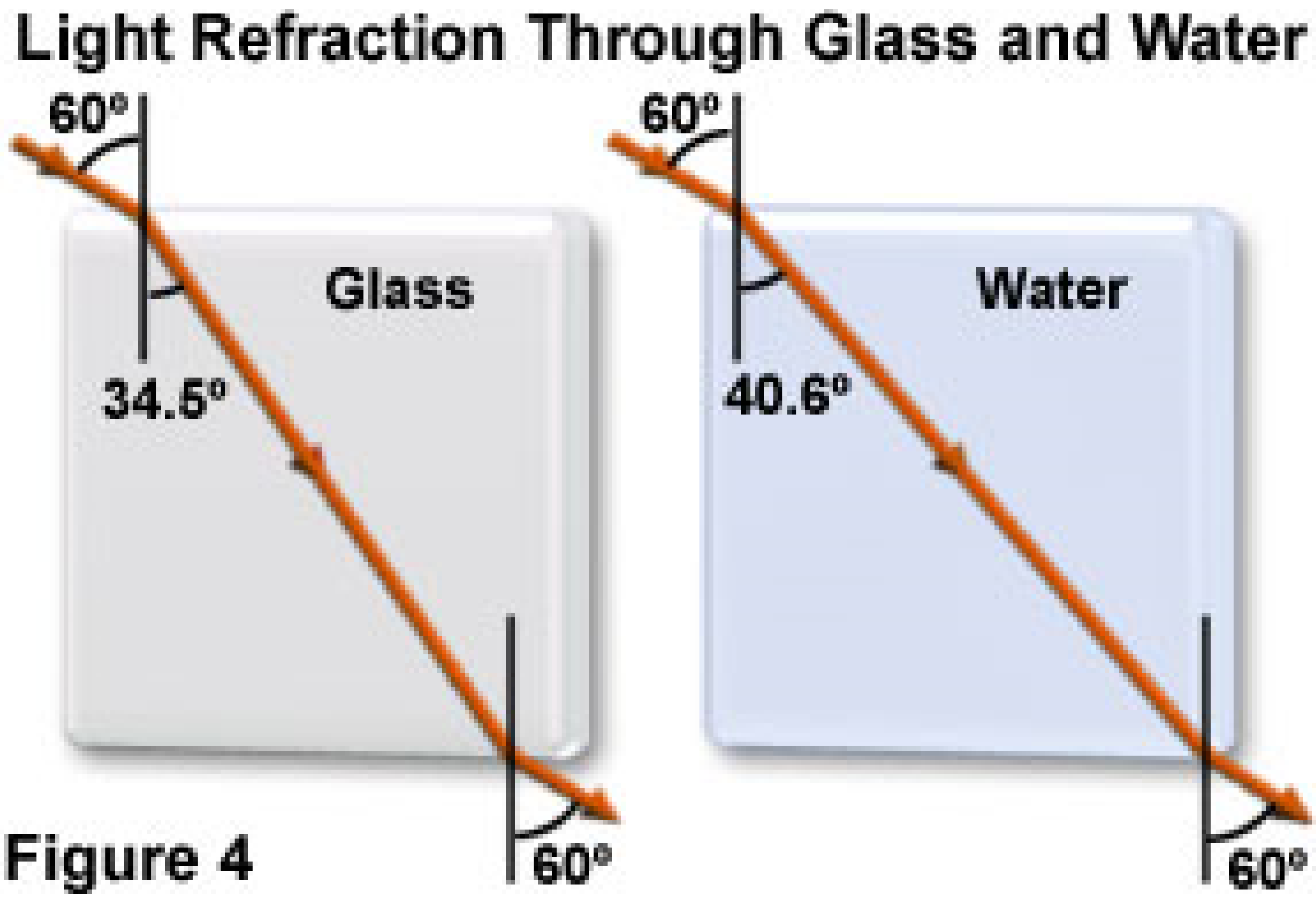


Figure 3



Light Refraction Through Glass and Water
60°
34.5°
Glass
60°
60°
40.6°
Water
60°

Figure 4

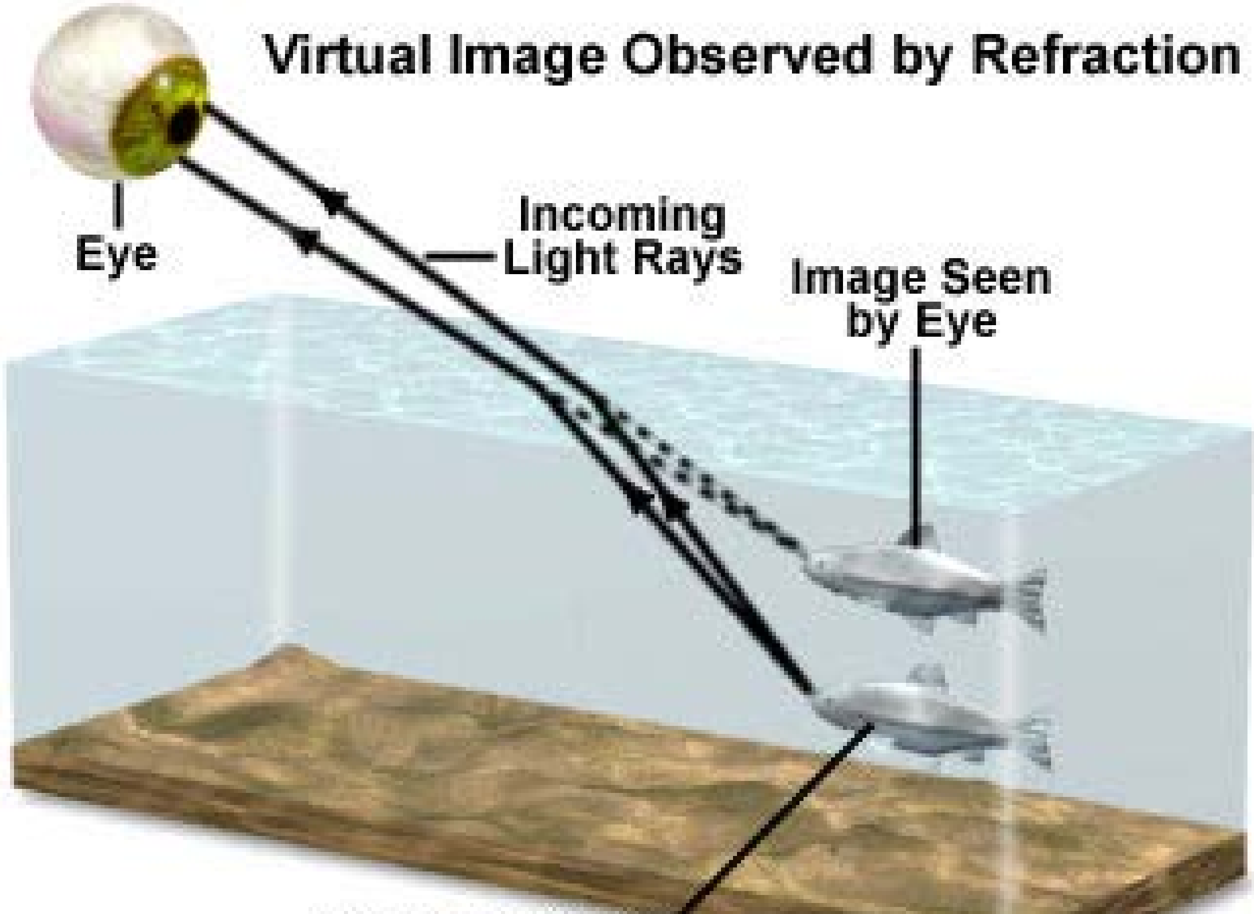

Virtual Image Observed by Refraction
Eye
Incoming
Light Rays
Image Seen
by Eye
Actual Position
of Fish

Figure 6

Image Formation with a Convex Lens

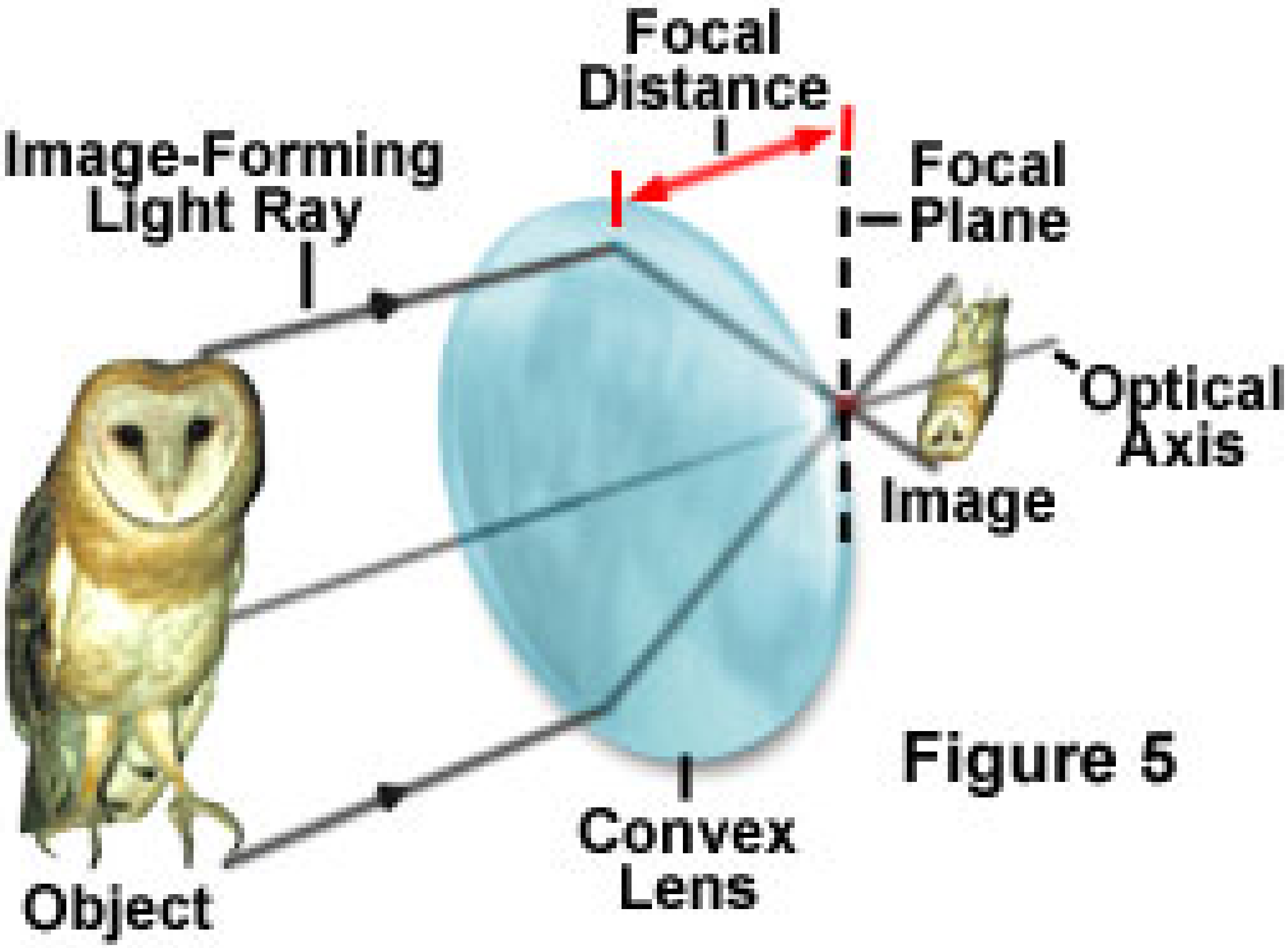
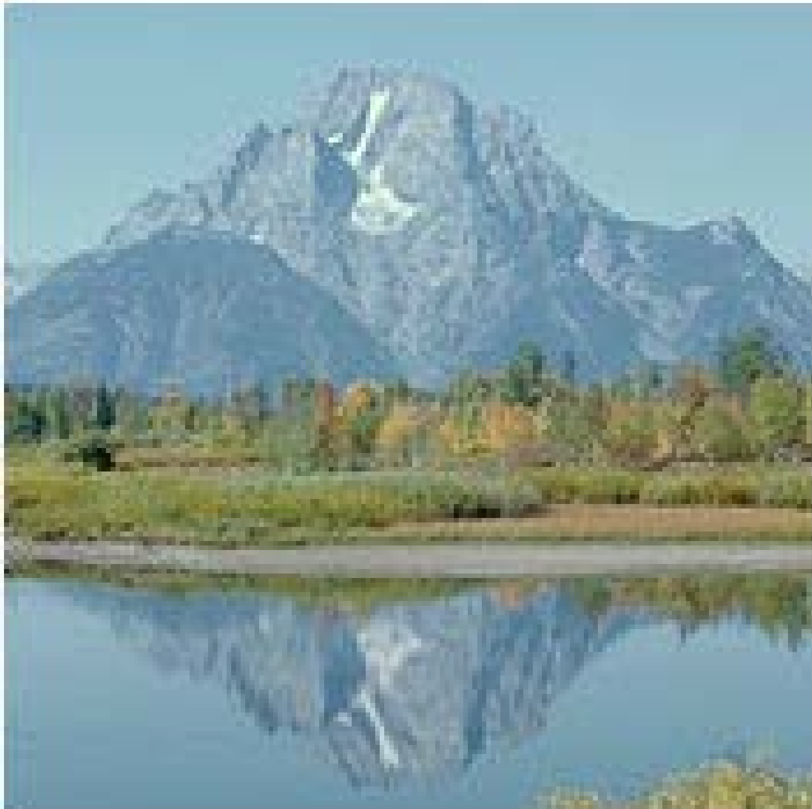


Figure 5

Reflection

Reflections From the Surface of Water



Smooth Water Surface

Wavy Water Surface

Figure 1

Reflection from Convex and Concave Surfaces

Figure 4

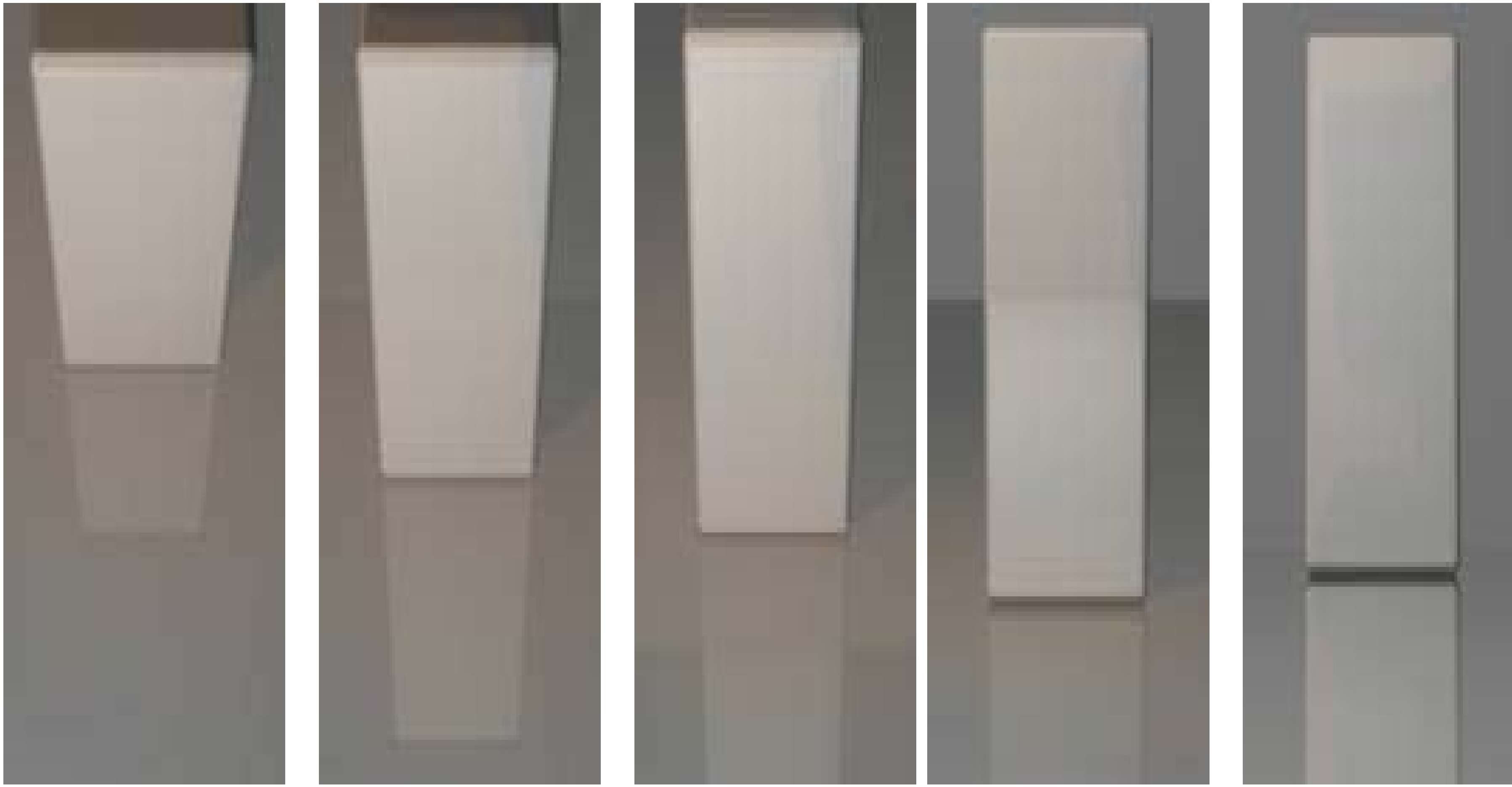
Outside Spoon Bowl

Inside Spoon Bowl

Experiment

Reflections from a shiny floor

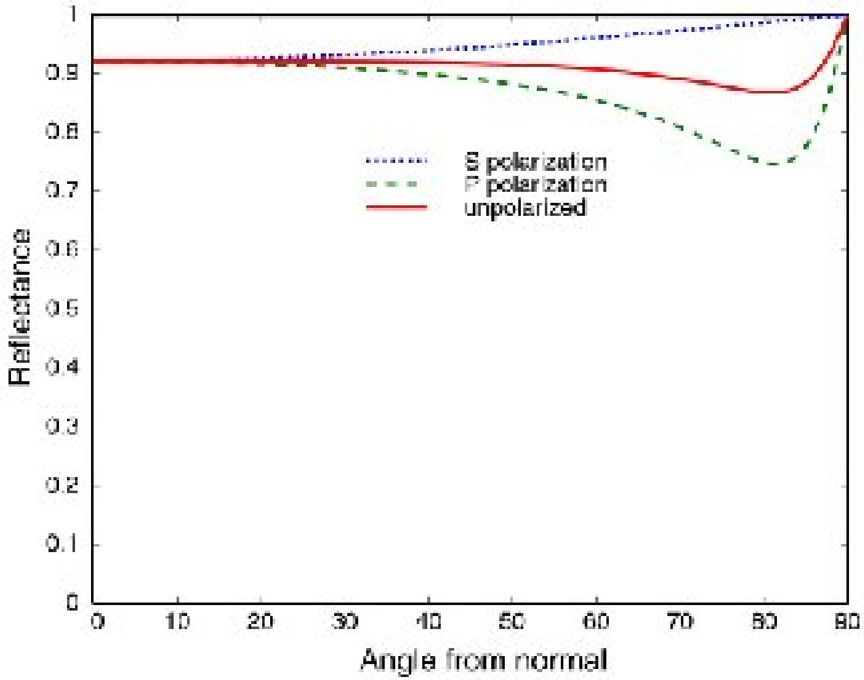
From Lafortune, Foo, Torrance, Greenberg, SIGGRAPH 97



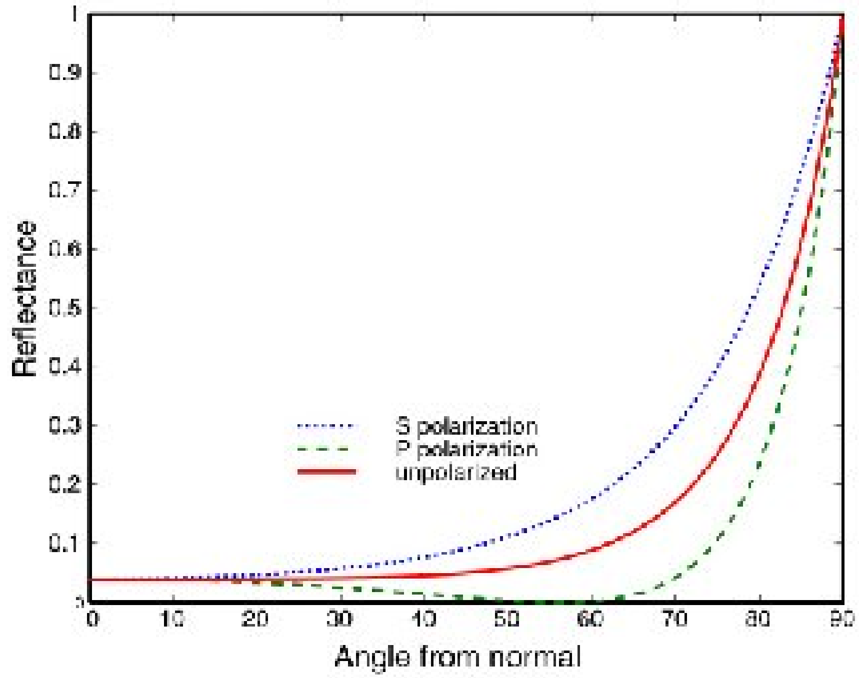
Really starts to be noticeable at less than 10-15° from the surface.

Fresnel Reflectance

Metal (Aluminum)



Dielectric (N=1.5)



Gold F(0)=0.82
Silver F(0)=0.95

Glass n=1.5 F(0)=0.04
Diamond n=2.4 F(0)=0.15

Schlick Approximation $F(\theta) = F(0) + (1 - F(0))(1 - \cos\theta)^5$

Fresnel Term

- Fresnel Term as found in text books is

$$F = \frac{1}{2} (\sin^2(\alpha-\beta)/\sin^2(\alpha+\beta)) + \tan^2(\alpha-\beta)*\tan^2(\alpha+\beta)$$

- Returns good results for strong reflecting water surfaces

Approximated Fresnel Term

- $F_0 = (N-1)^2/(N+1)^2$ is a minimum of incoming light parallel to the normal of the surface.

- $F_\alpha = F_0+(1- \cos(\alpha))^5 * (1- F_0)$ is a value between 0 and 1 depending on the angle between the incoming ray and the surface normal.

- e.g. $F_{90} = 1$, if the incoming ray is parallel to the surface, all light is reflected.

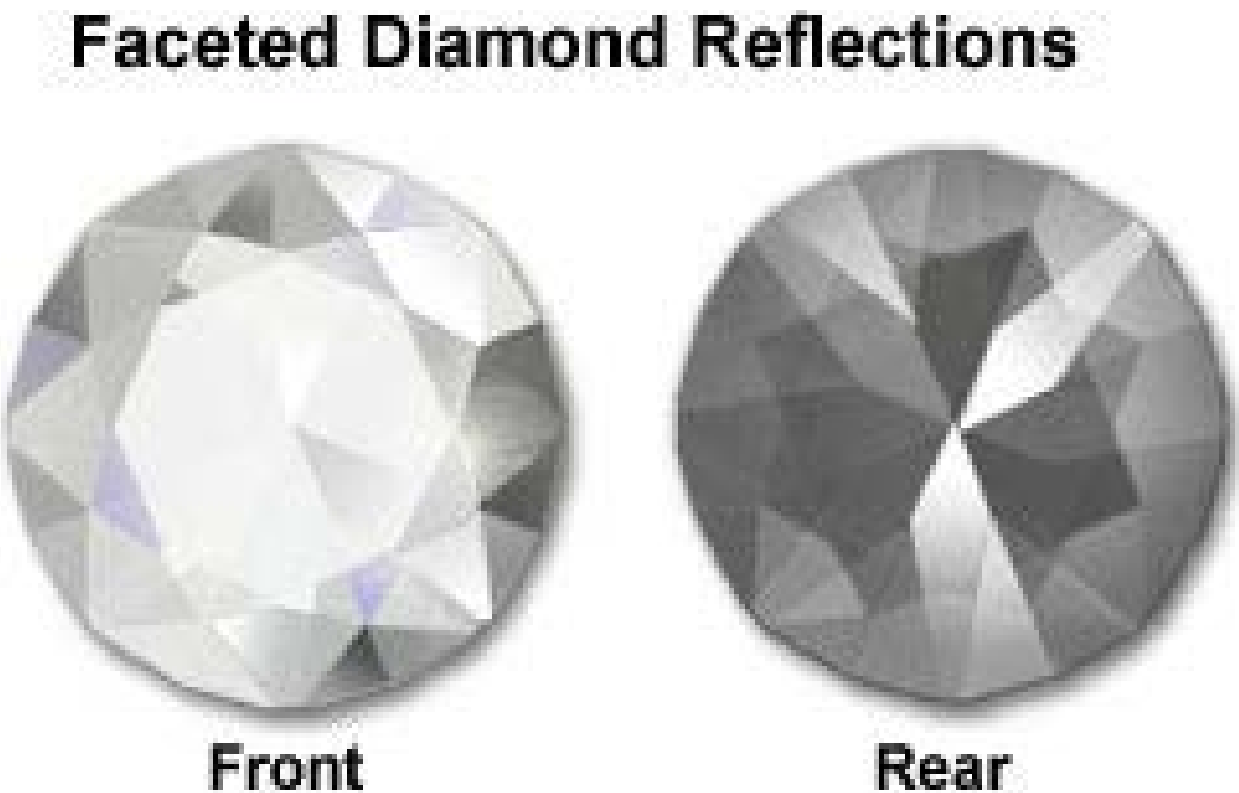


Figure 6

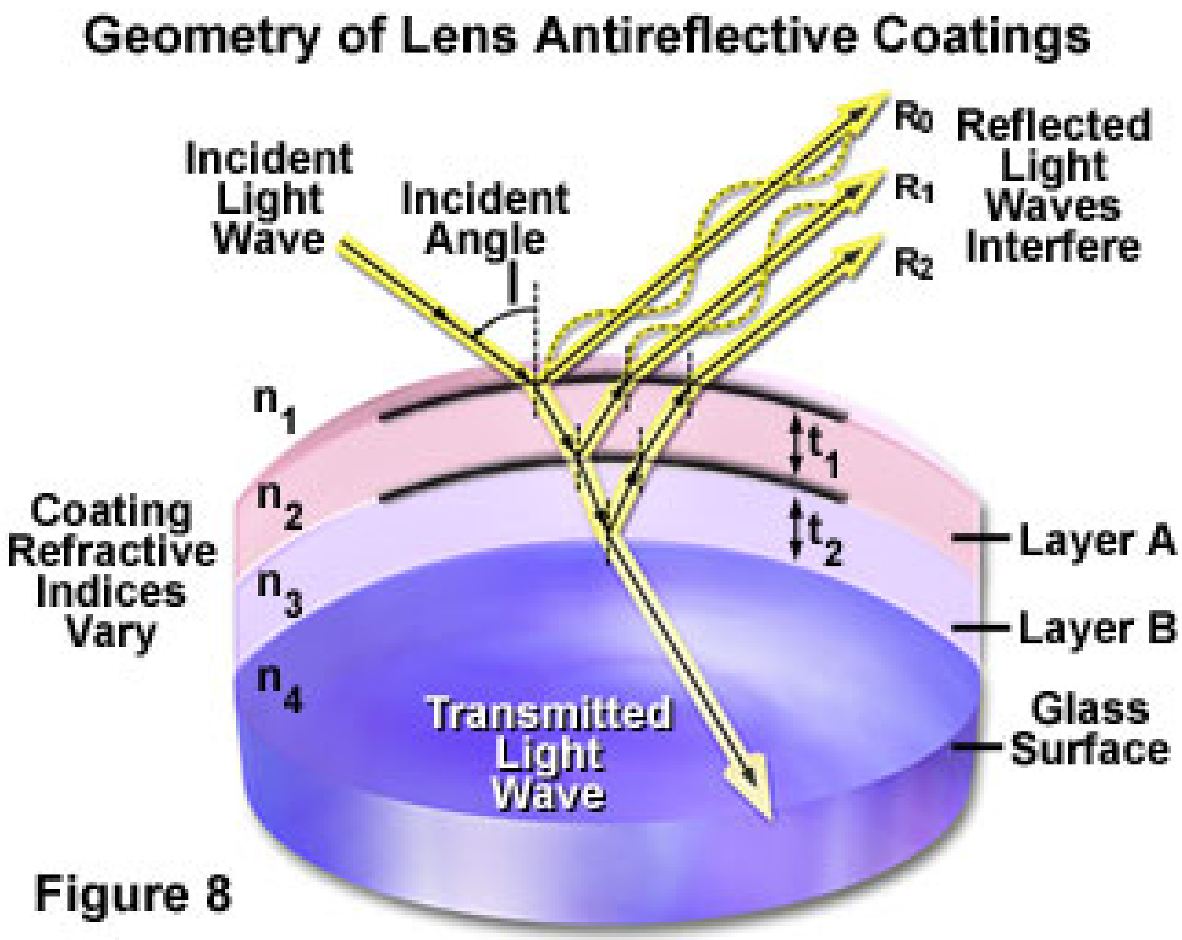
Designed to reflect all light eventually to Observer.

Anti-reflective Coatings

- Reduce unwanted, stray reflections
- Use material coatings on glass to reduce reflection and maximize transmission.
- Take advantage of destructive light interference.

"One of the most significant advances made in modern lens design, whether for microscopes, cameras, or other optical devices, is the improvement in antireflection coating technology."

Anti-reflective Coatings



Magnesium fluoride very commonly used on Lenses, Microscopes

Refractions or Reflections?

Refractions or Reflections Confusion

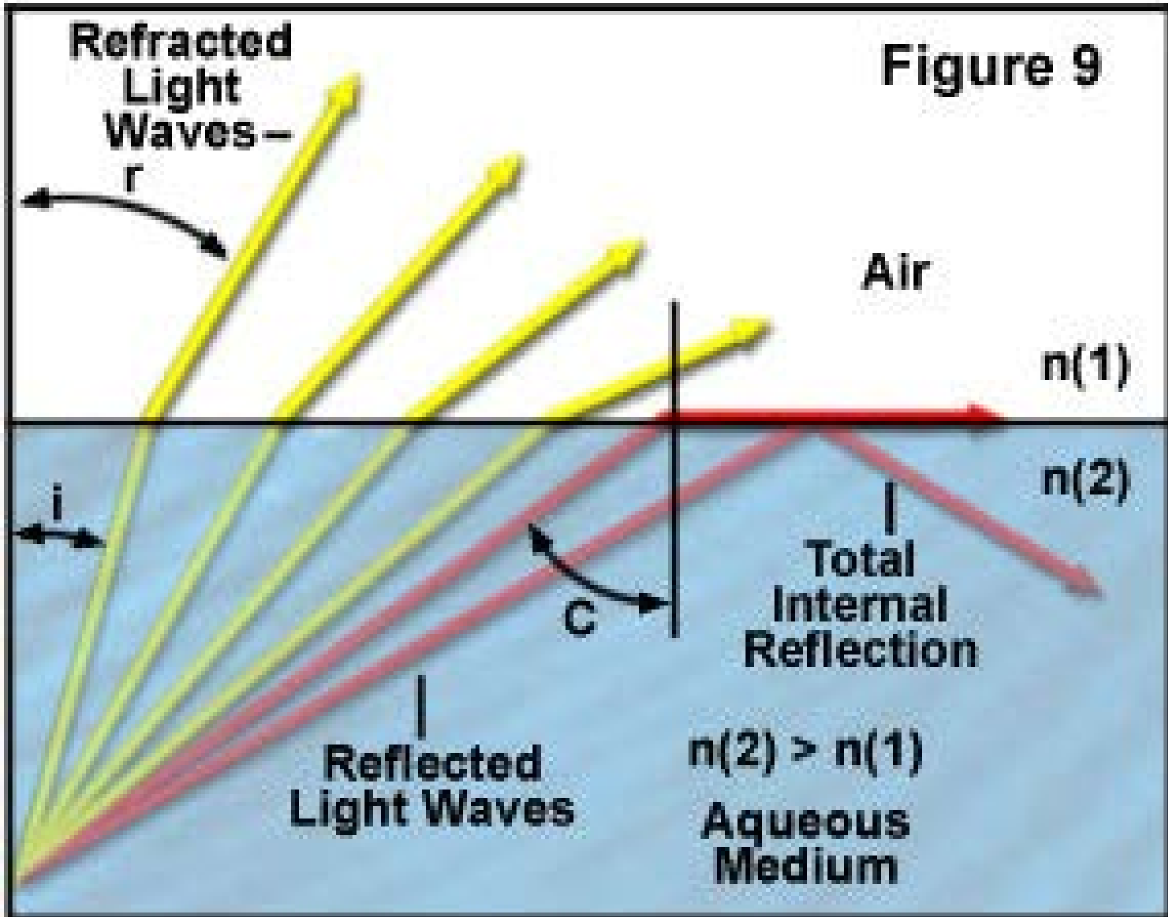
Why do you see shiny roads when
they are diffuse and are not wet?

Why do you see apparent reflections in deserts?

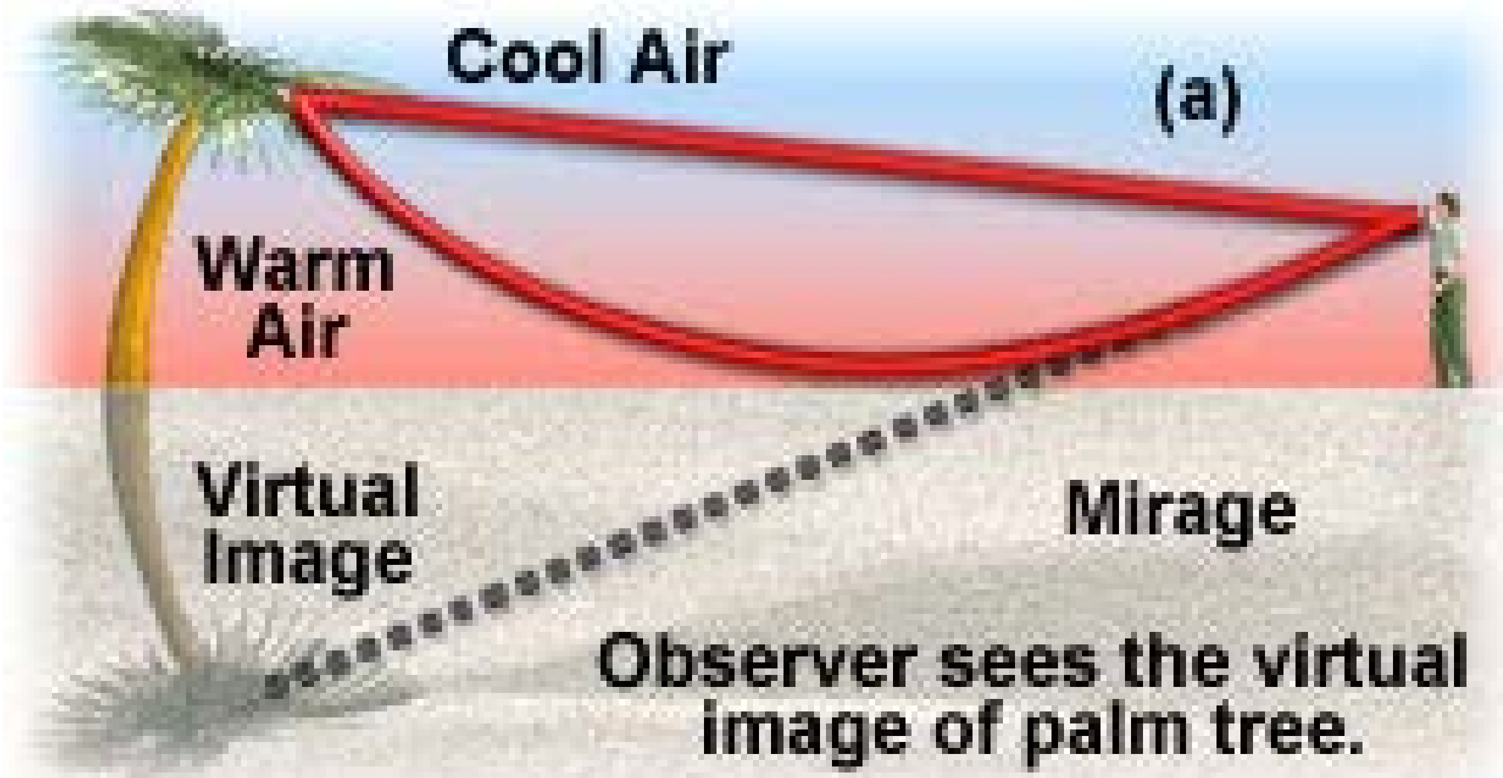
Where else do you see apparent reflections?

Do you see reflections above objects???

Reflection at the Critical Angle



Mirage and Looming Artifacts



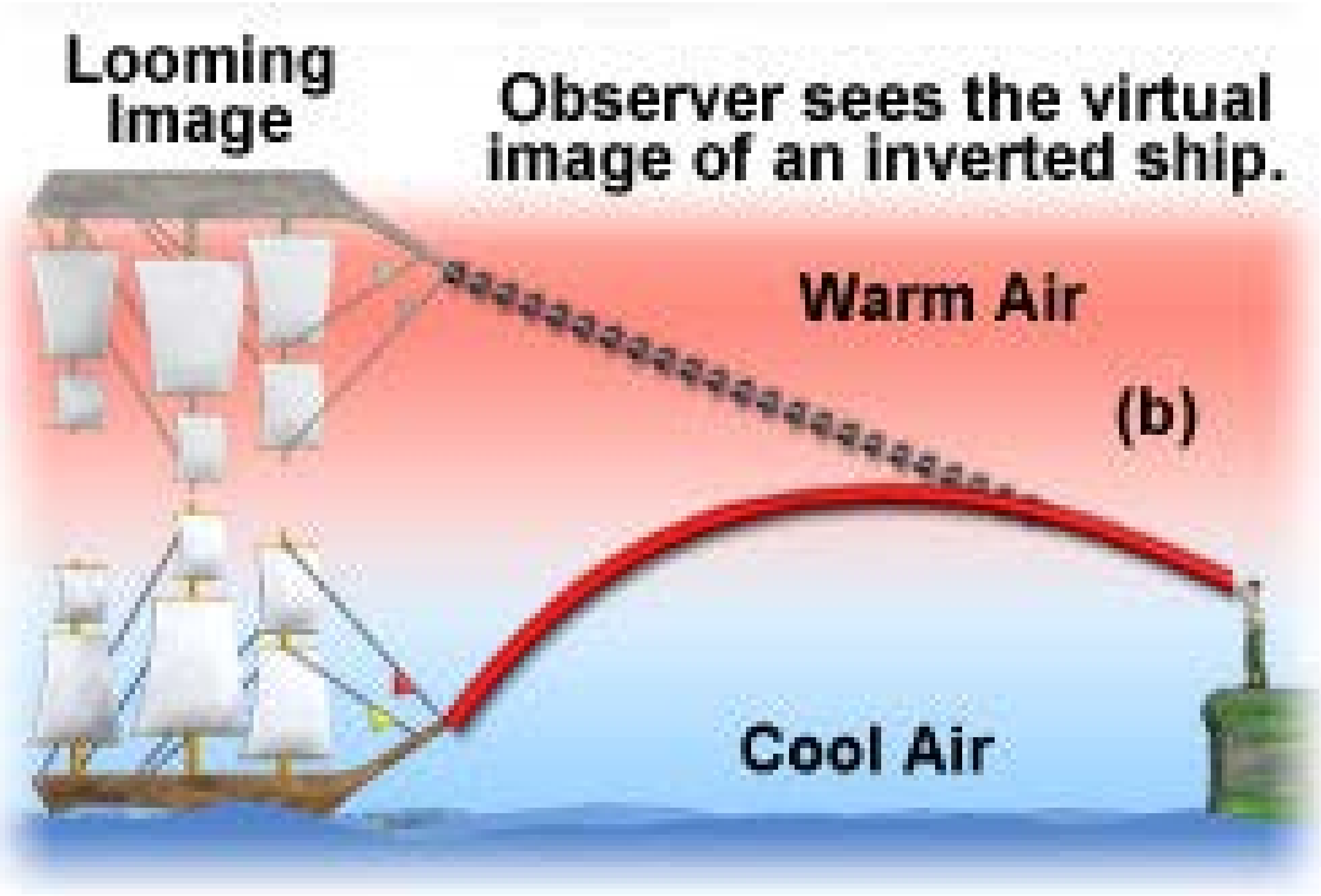
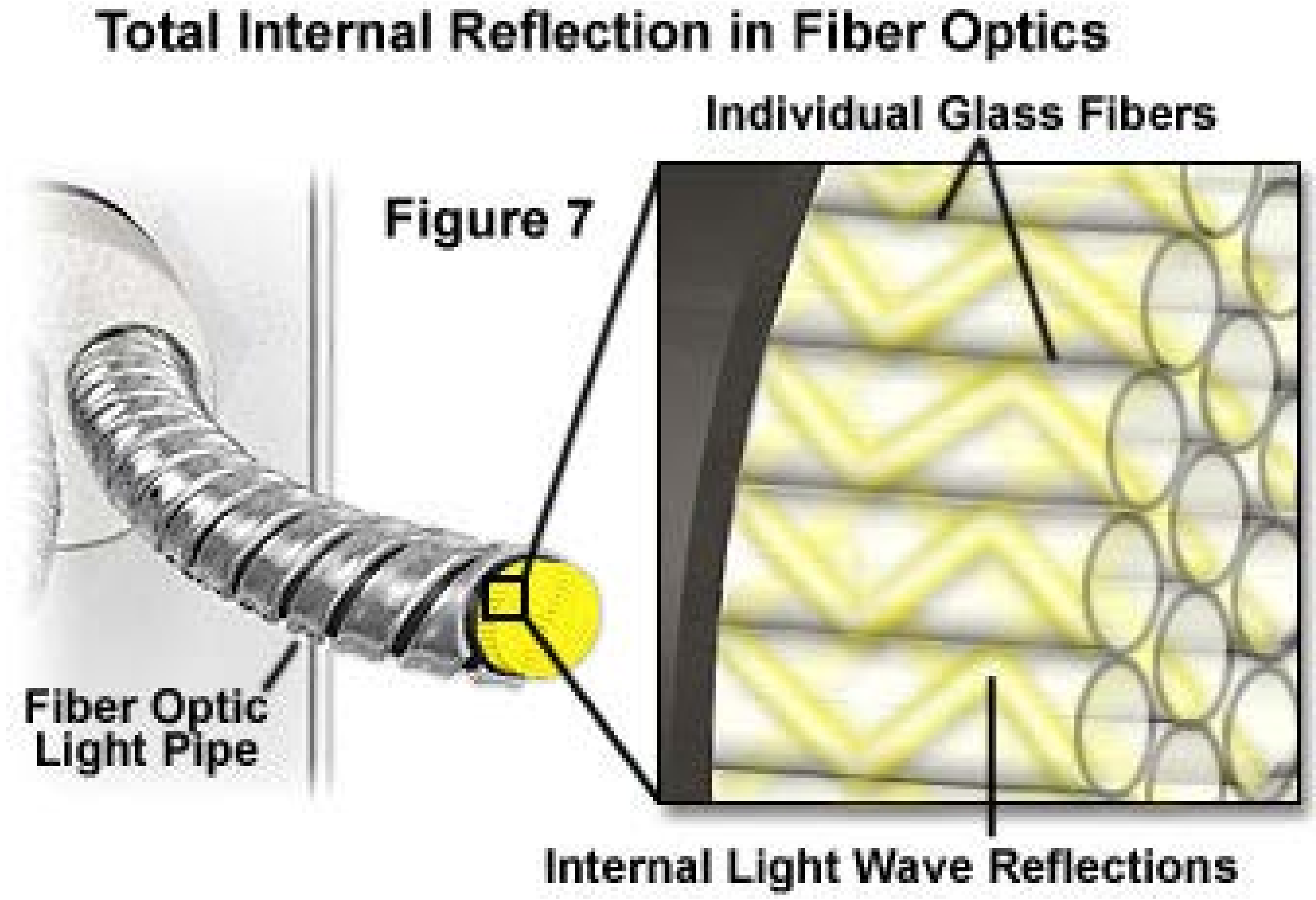

Looming
image
Observer sees the virtual
image of an inverted ship.
Warm Air
(b)
Cool Air

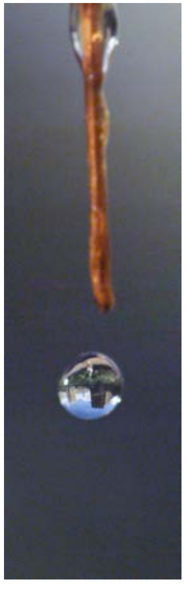
Figure 7



Used in Endoscopy, Communications

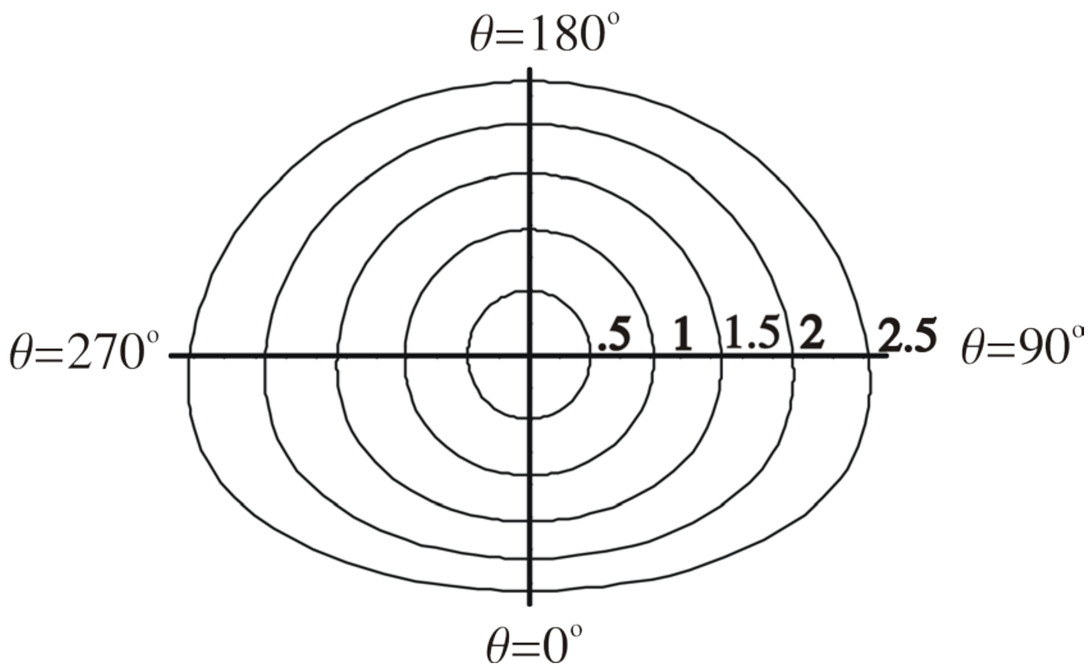
Water Drops : Refractions + Reflections

A Drop and its Environment.



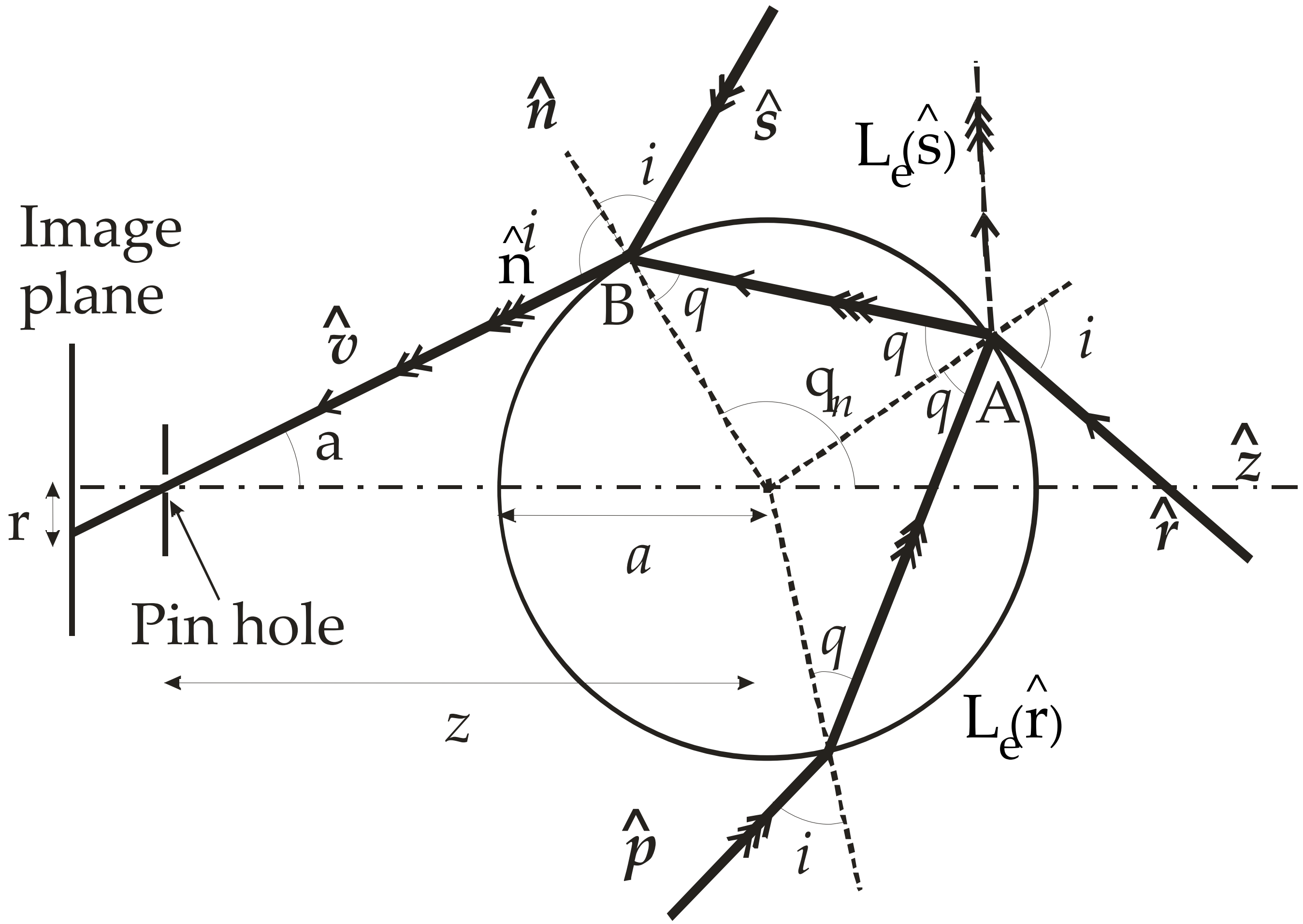
World in a drop

Shapes of falling drop

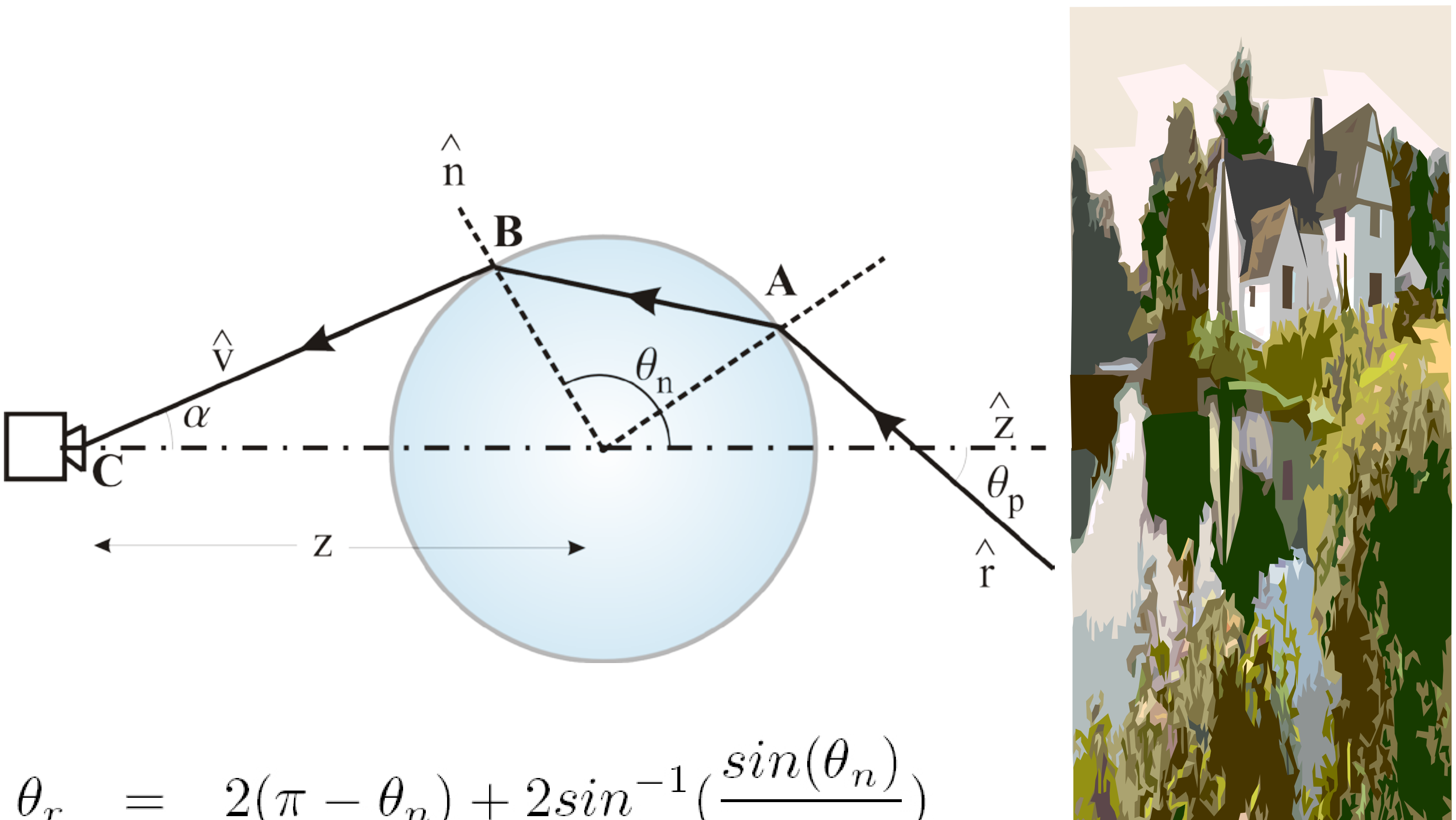


Shapes of falling drop

Refraction and Reflection



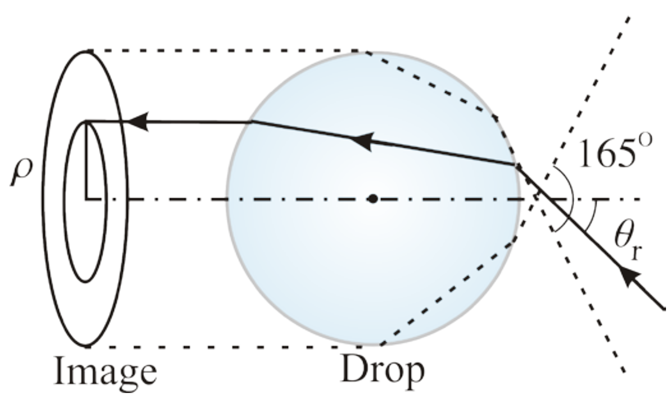
Refraction

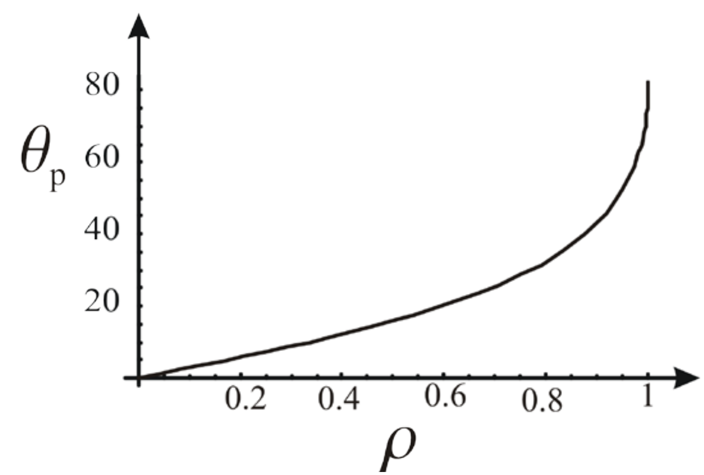


$$\theta_r = 2(\pi - \theta_n) + 2sin^{-1}(\frac{sin(\theta_n)}{\mu})$$

$$\phi_r = \pi + \phi_n \; .$$

Geometric mapping

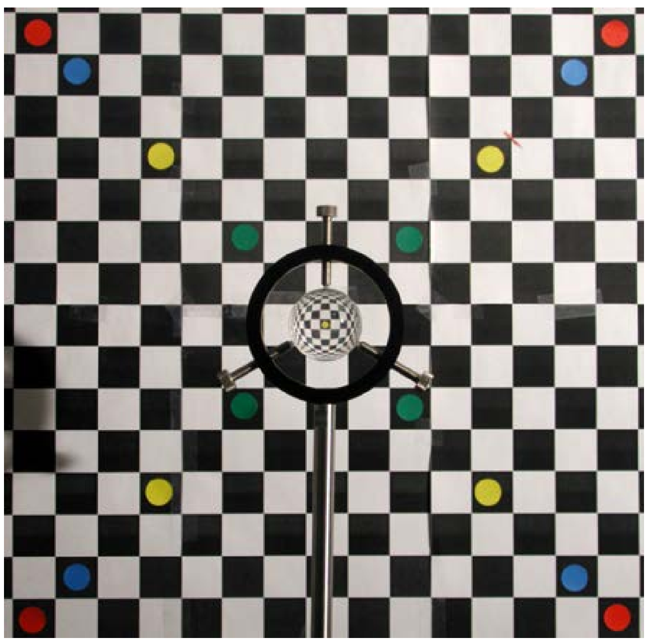




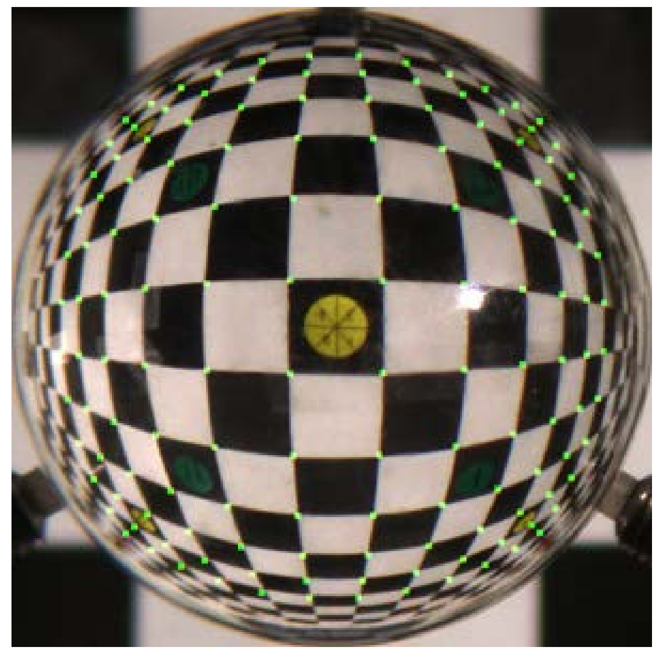
fov=165 degrees

$$\rho = m\, a\, sin\, \theta_n\,, \quad \phi = \phi_n\,.$$

Experiments: Refraction

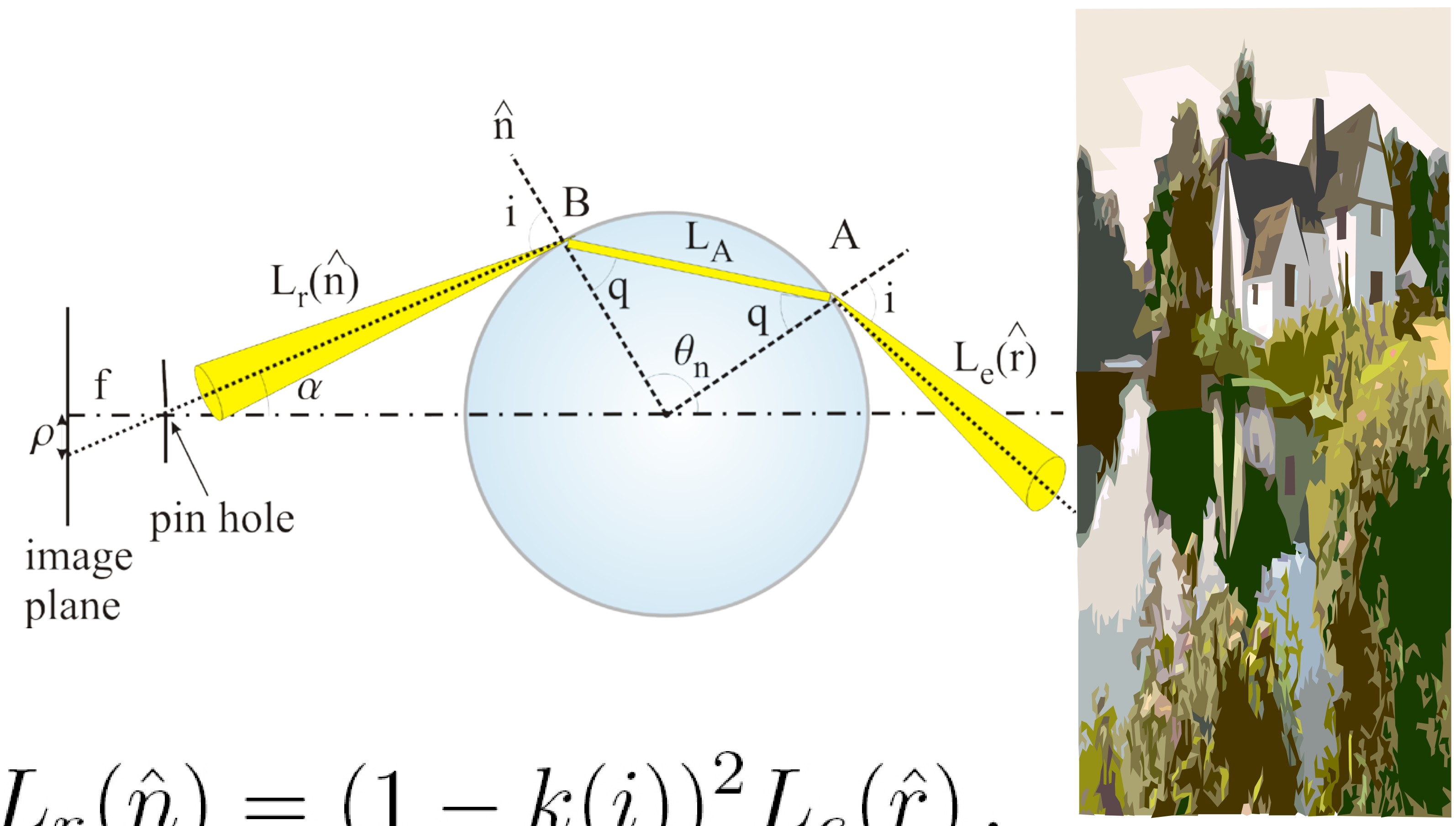


Experimental setup



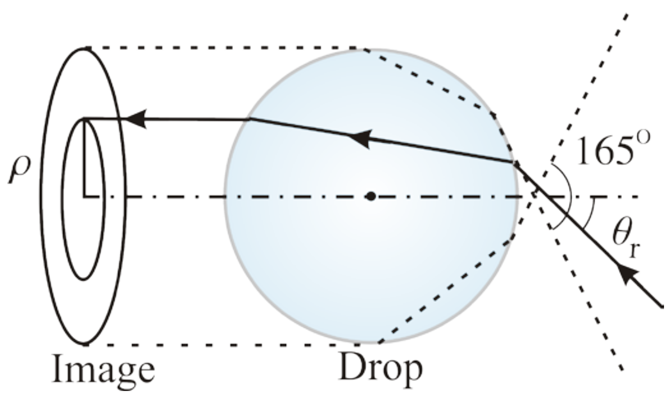
Calculated corners are in green

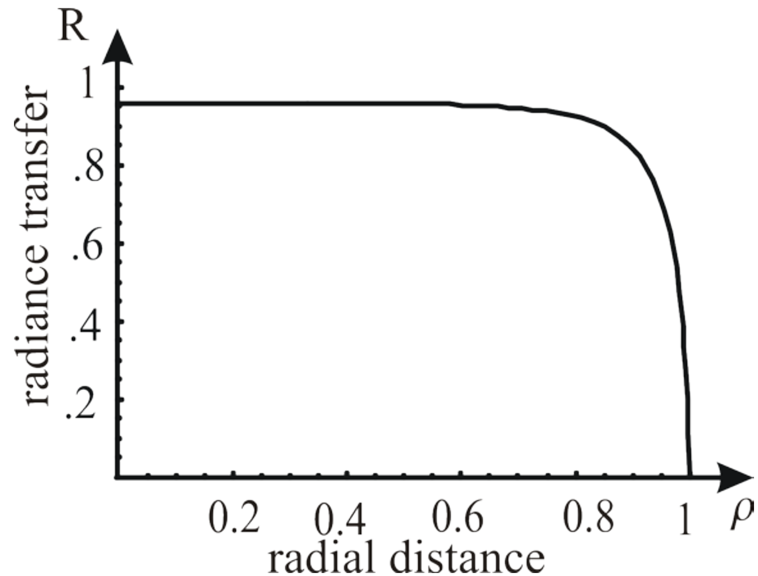
Photometry of Refraction



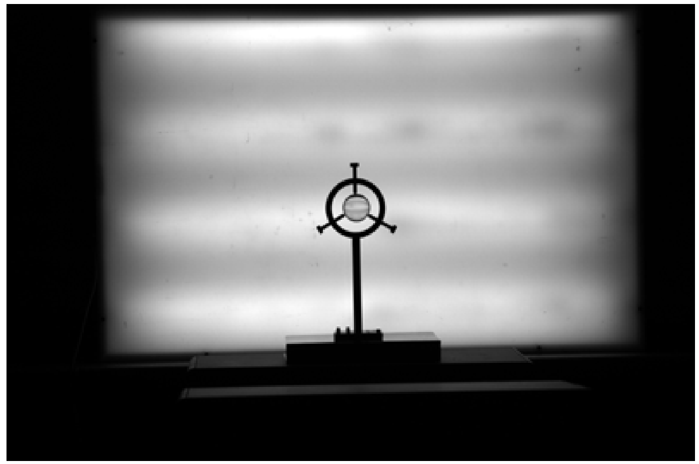
$$L_r(\hat{n}) = (1 - k(i))^2 L_e(\hat{r}) \, .$$

Plot of Transmitted Radiance

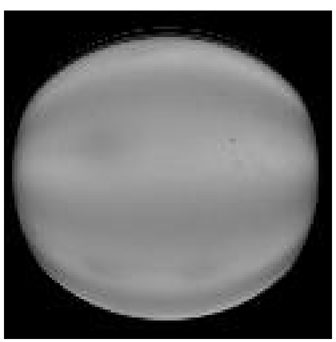




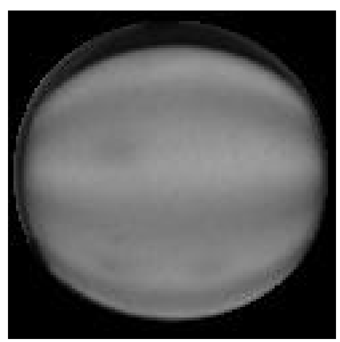
Experiment: Photometry of Refraction



Experimental Setup



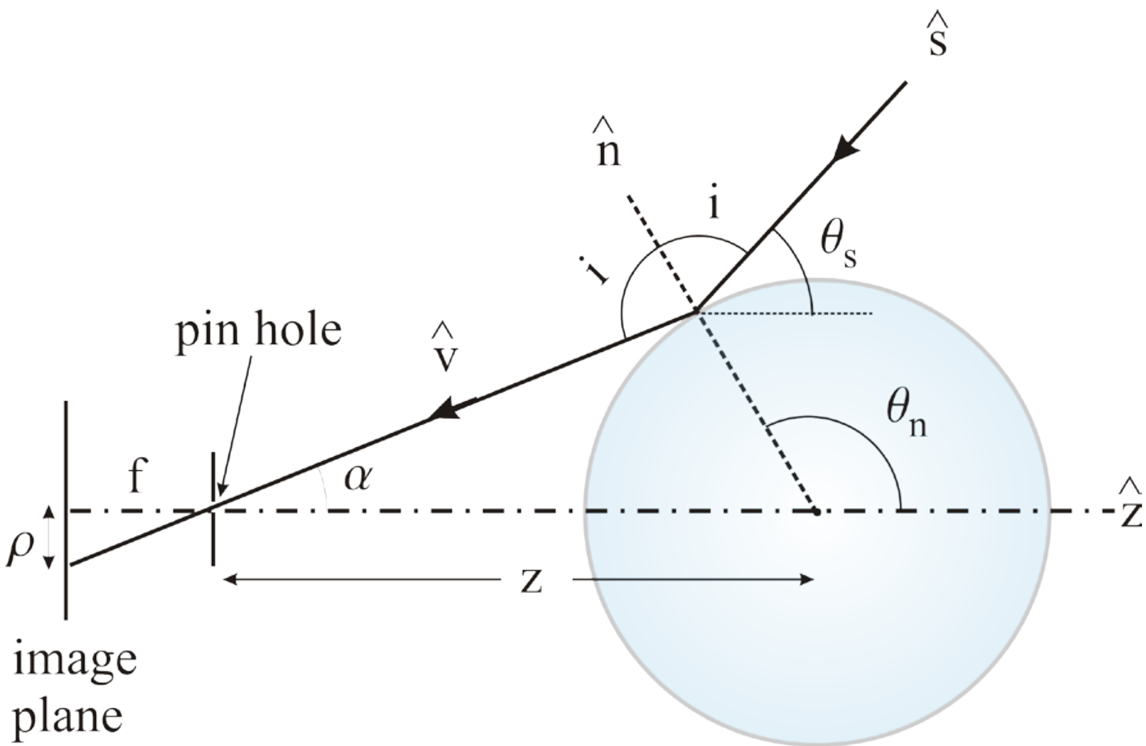
Rendered



actual image

difference image

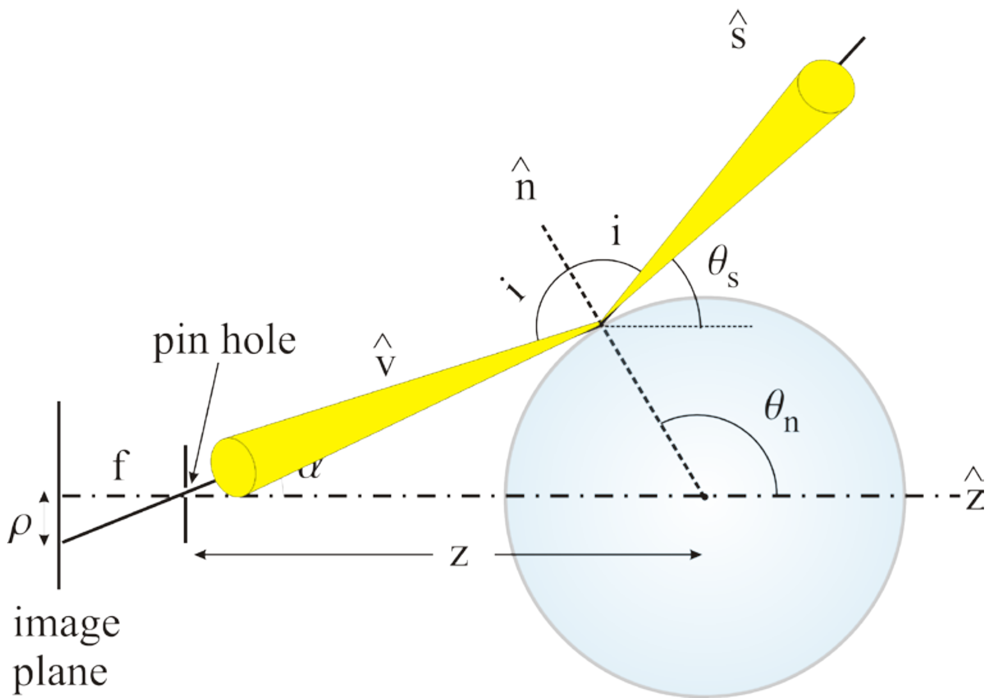
Reflection



$$\theta_s = 2\theta_n - \pi$$

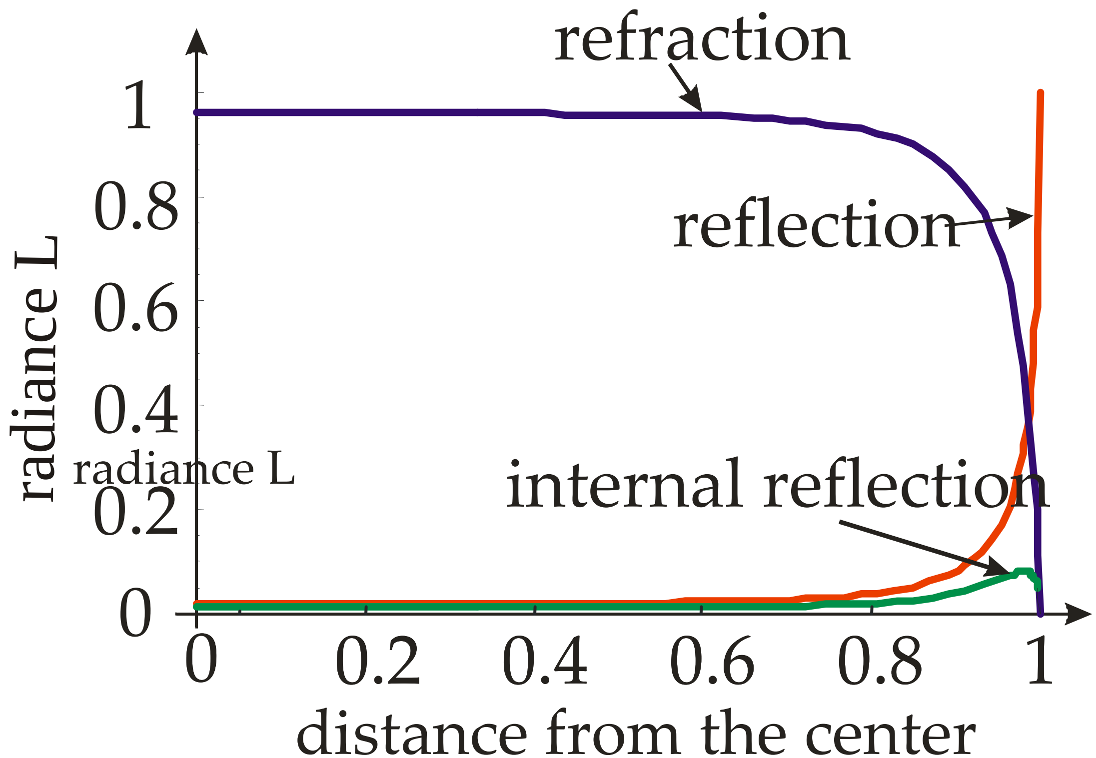
$$\phi_s = \pi + \phi_n.$$

Photometry of Reflection



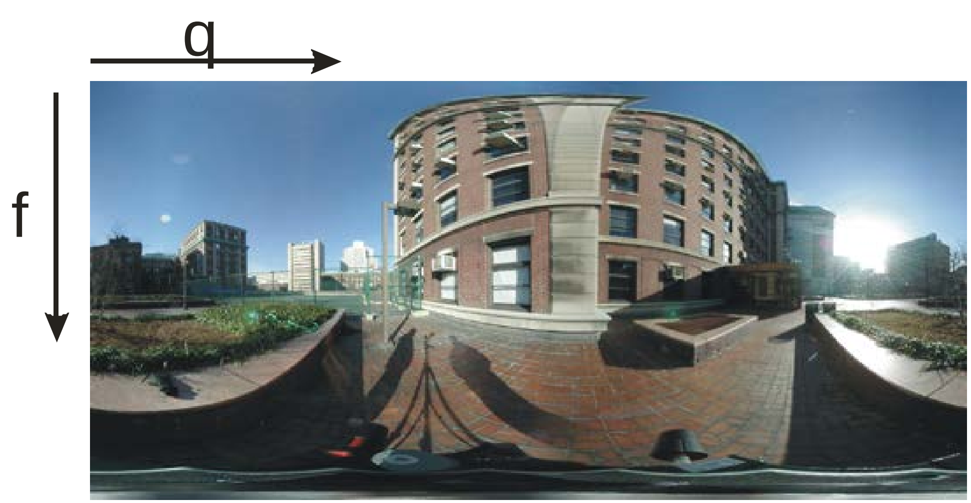
$$L_s(\hat{n}) = k(i)L_e(\hat{s})$$

Reflection vs. Refraction

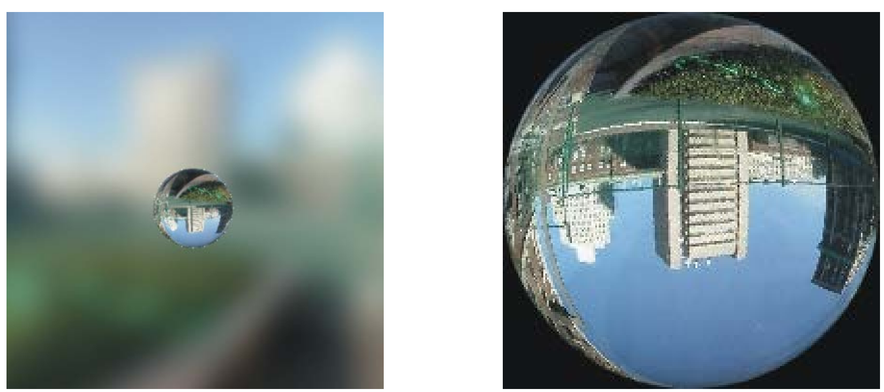


$$L(\hat{n}) = (1 - k(i))^2 \, L_e(\hat{r}) + k(i) \, L_e(\hat{s})$$

Rendering a Rain drop

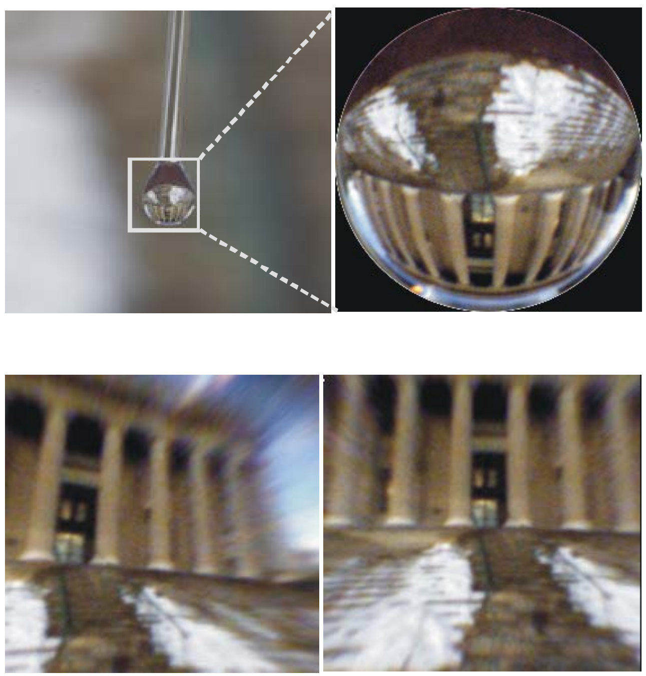


Environmental Illumination

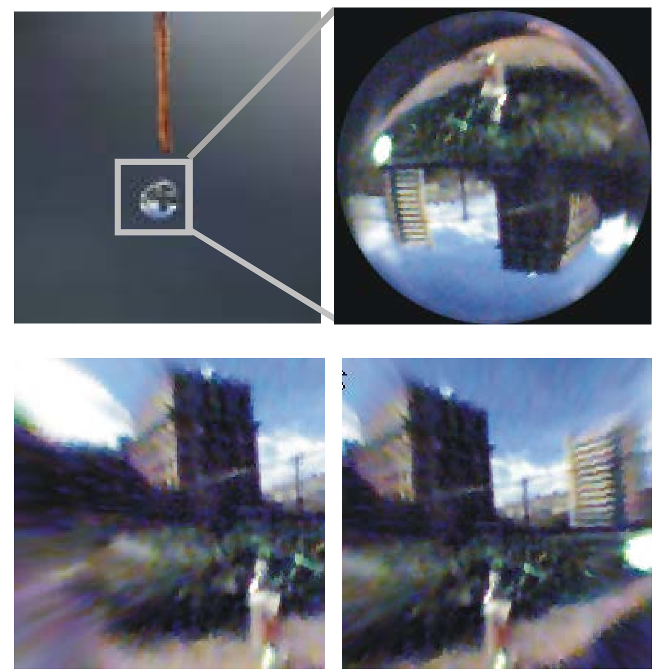


Rendering a Drop

World in a Rain Drop



Low Library

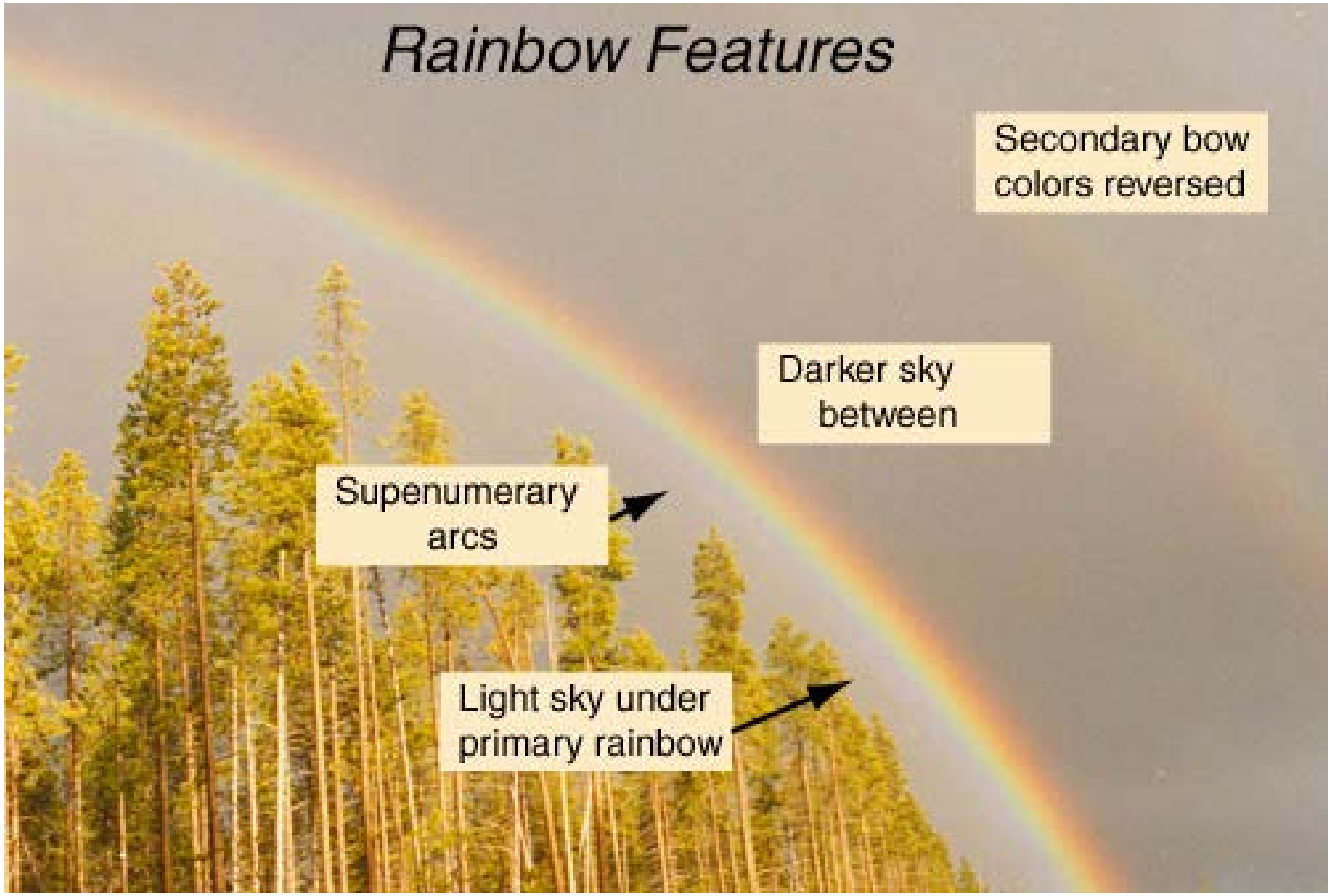


Pupin Hall

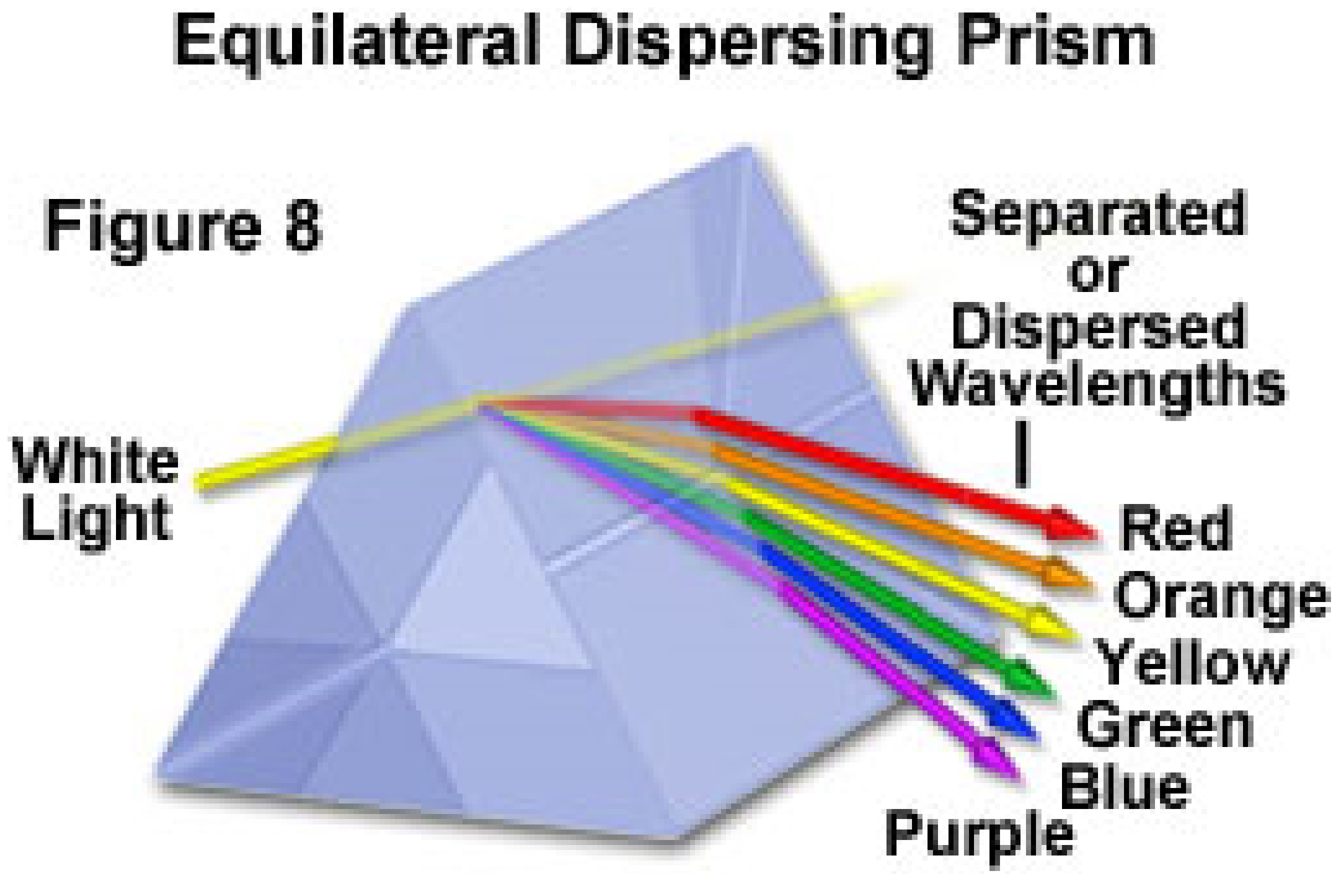
Tired of water drops?

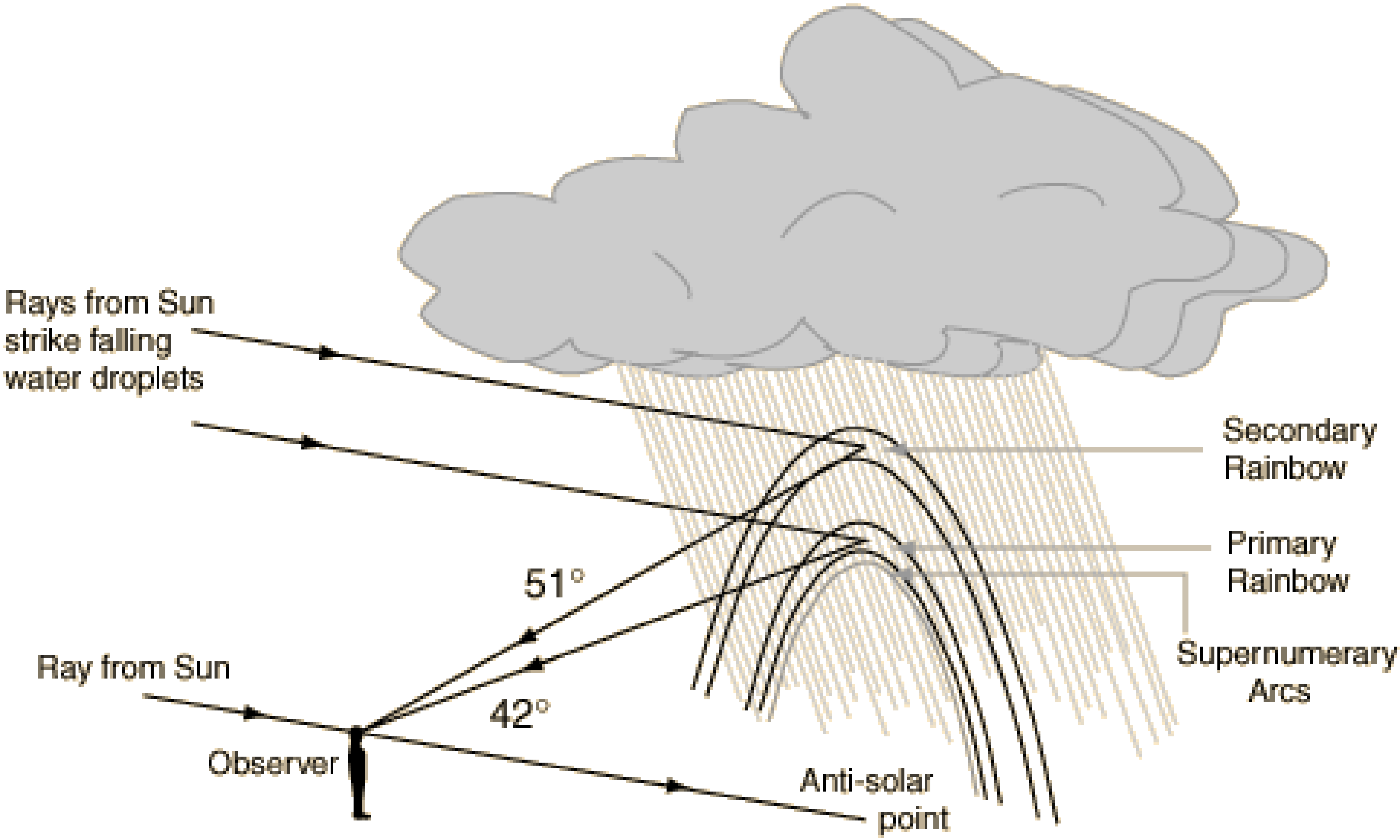
Wait, there’s more…

Rainbows : Refractions + Reflections + Wavelength of Light


Rainbow Features
Secondary bow colors reversed
Darker sky between
Supenumerary arcs
Light sky under primary rainbow

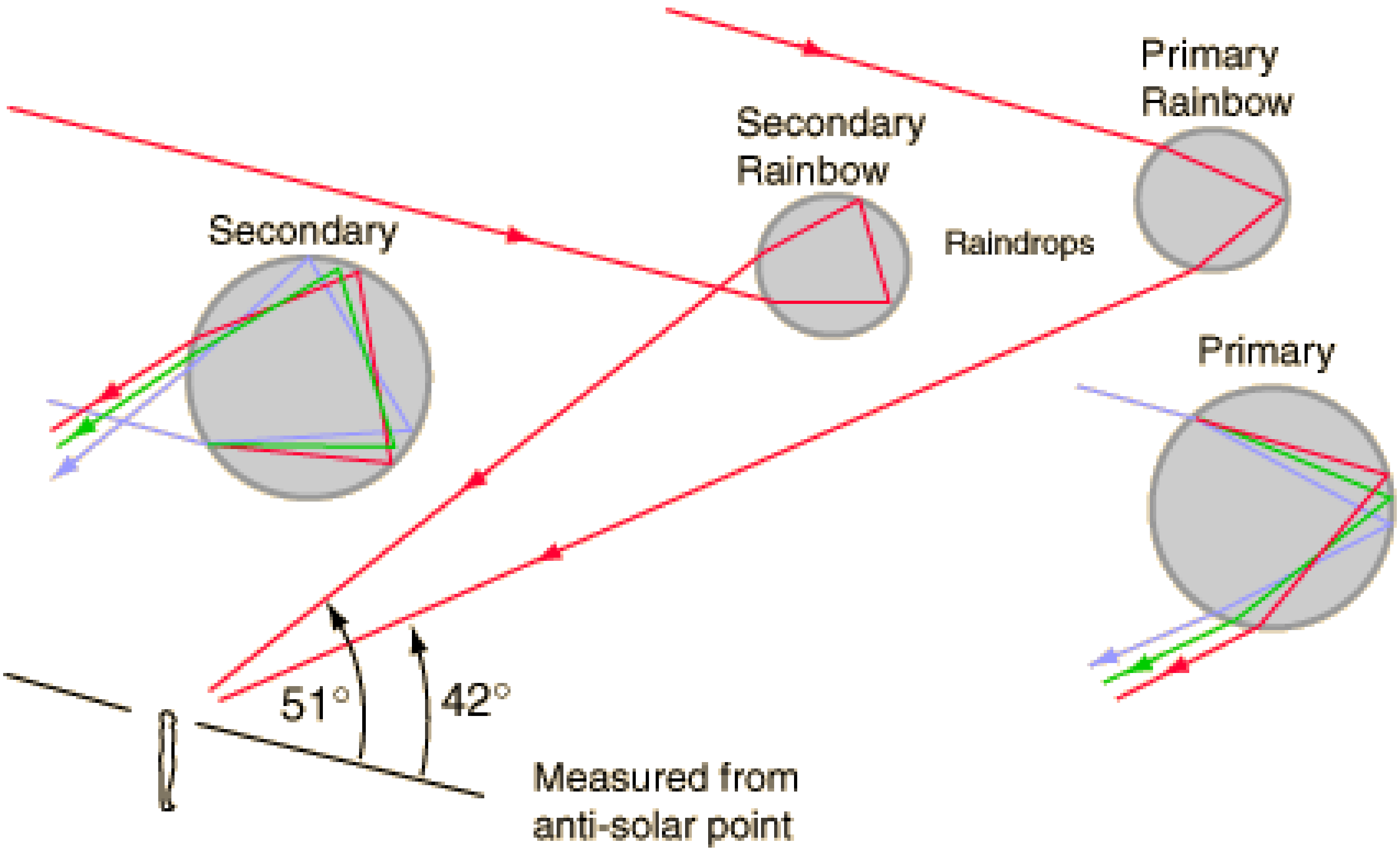
Visible Light Wavelength Dispersion





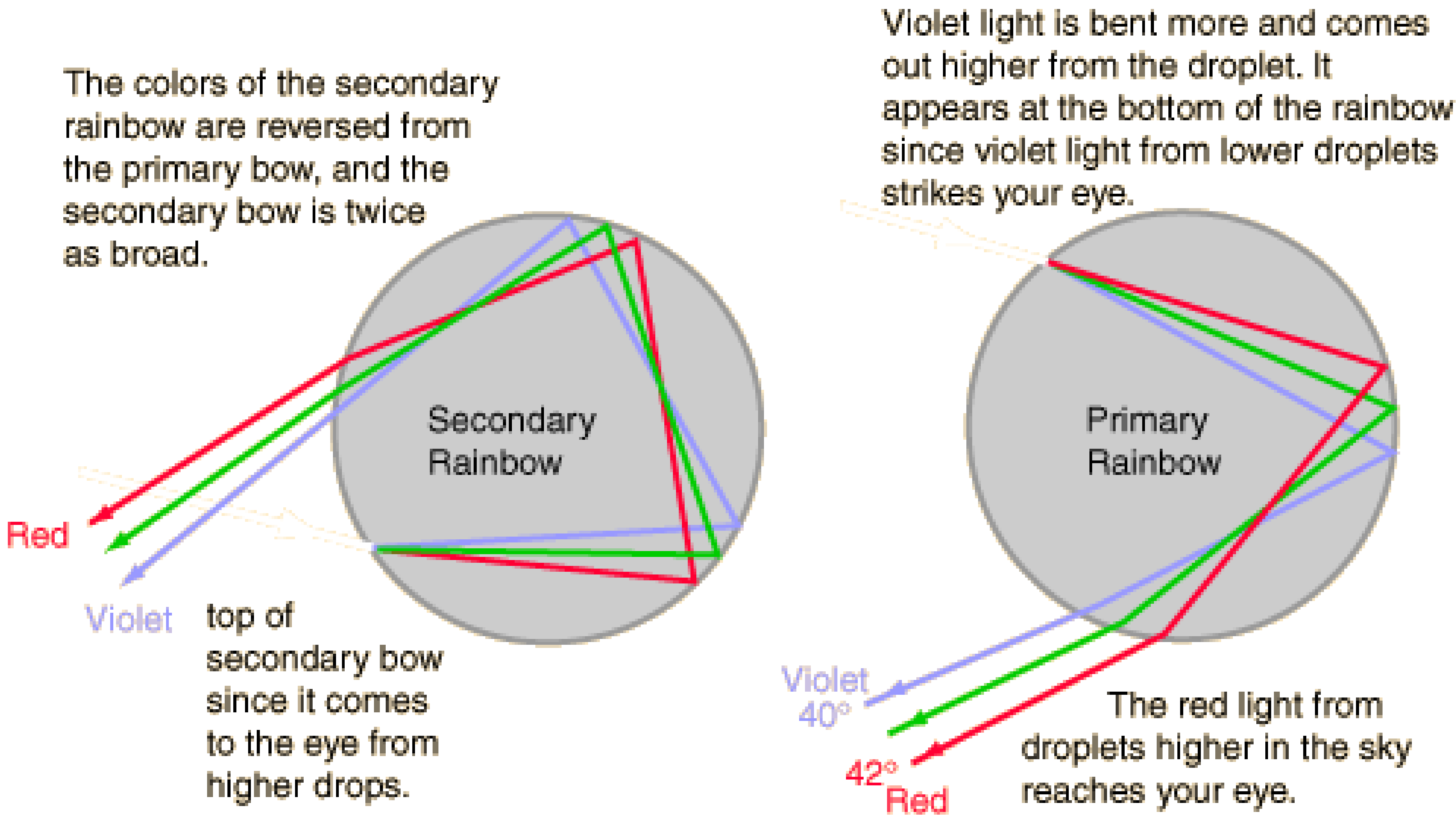
Can you see rainbows during midday?

Why are there two rainbows?



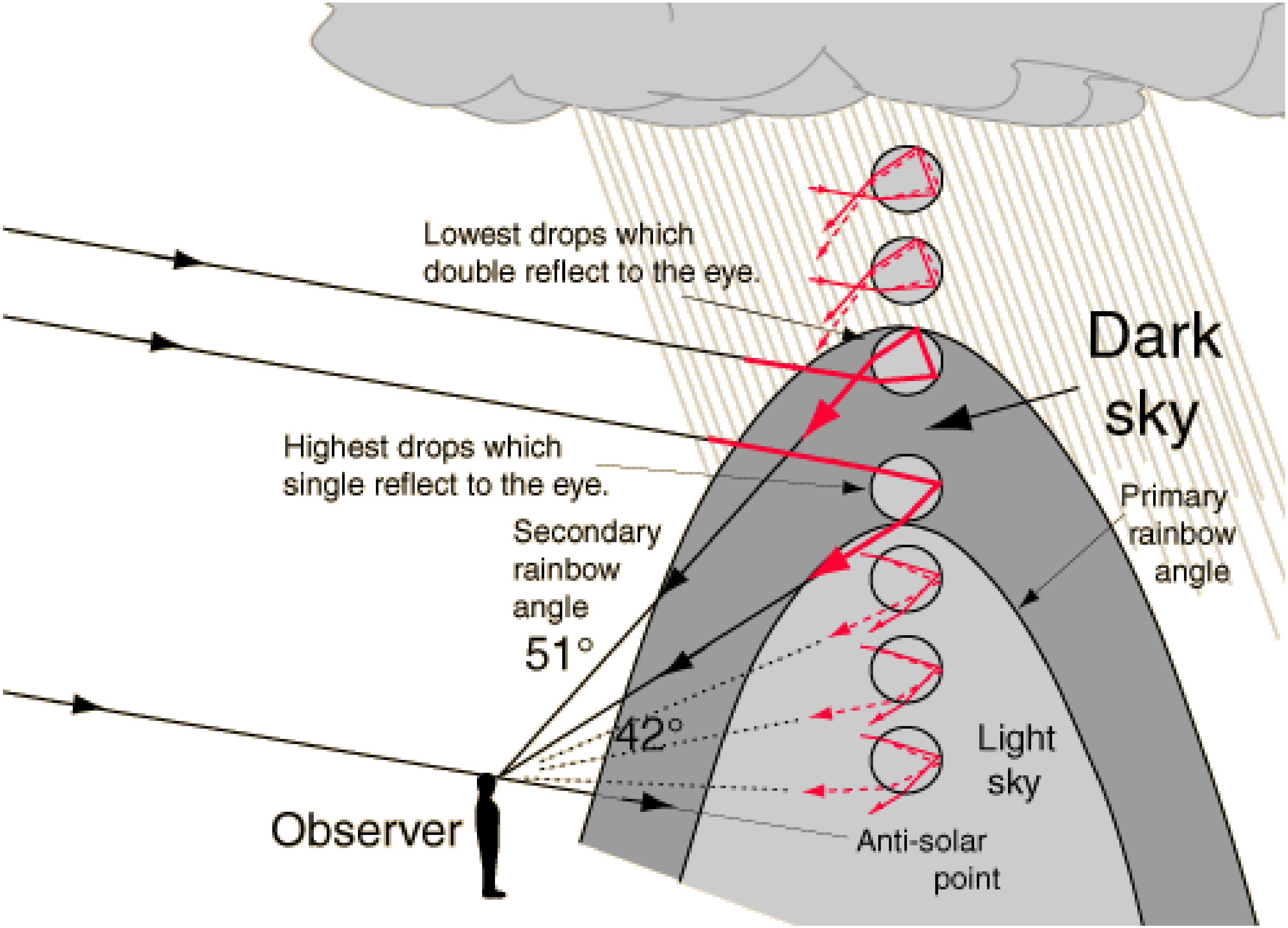
Are there only two rainbows?

Why the color pattern?



Bright Sky under and Dark above the Rainbow

Photo by Ben Lanterman taken immediately after
a heavy rainstorm when the air was quite saturated at 4PM.

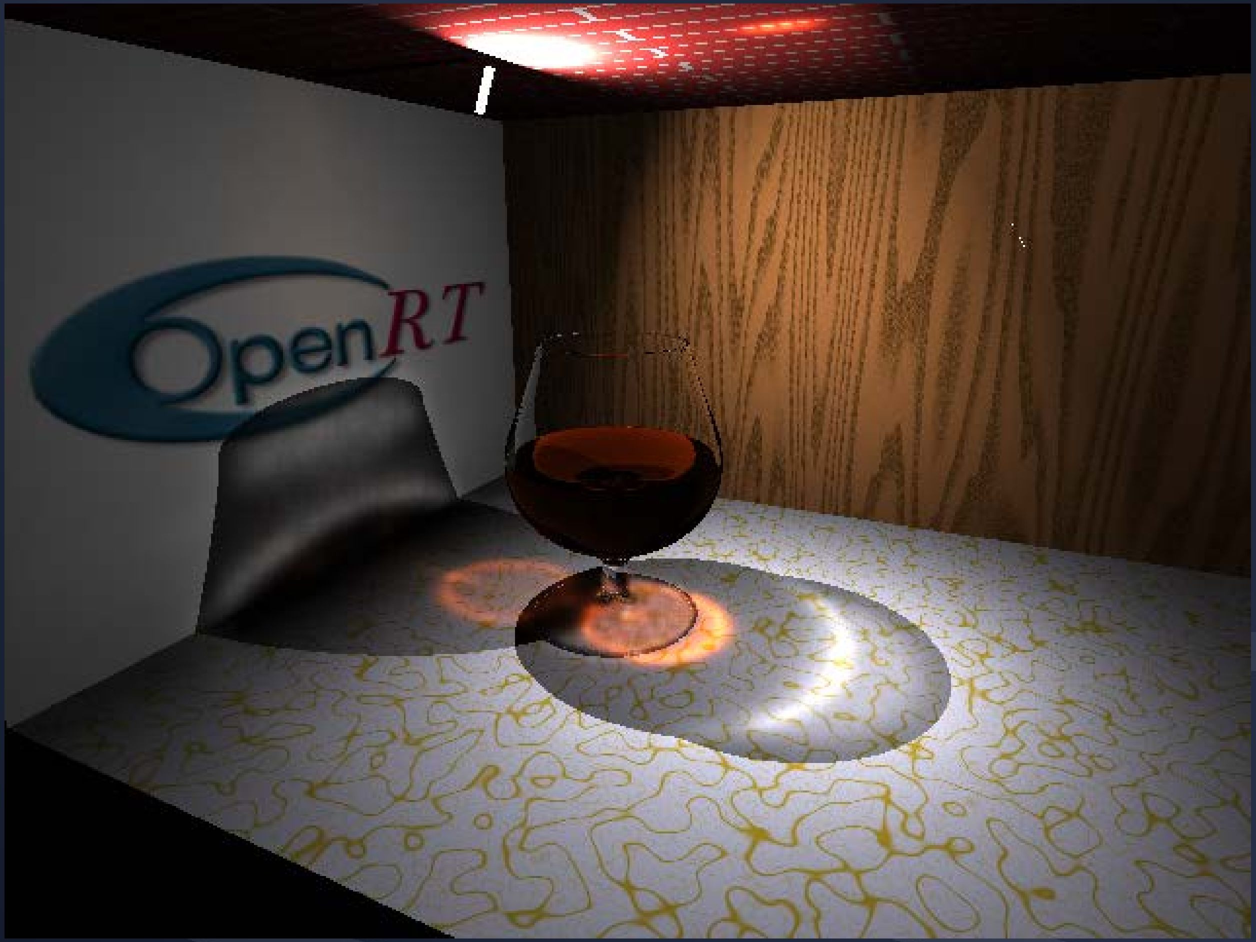

Lowest drops which
double reflect to the eye.
Dark
sky
Highest drops which
single reflect to the eye.
Secondary
rainbow
angle
51°
Primary
rainbow
angle
42°
Light
sky
Observer
Anti-solar
point

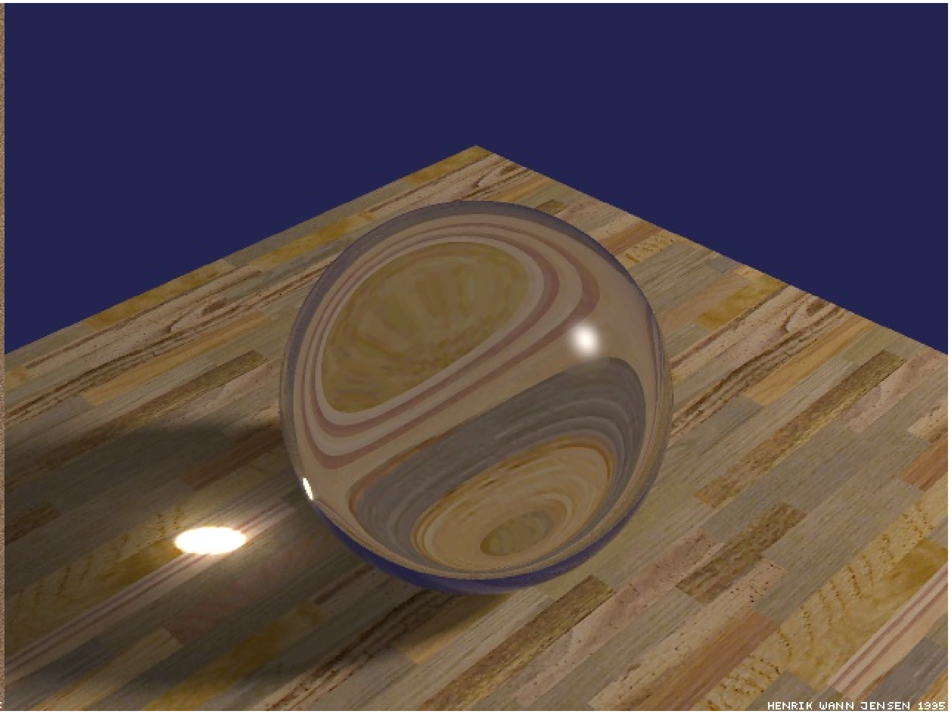
Caustics: Bunching up
Reflections or Refractions

- What is wrong with this rendering?

Computer Graphik Universität des Saarlandes

- With caustics

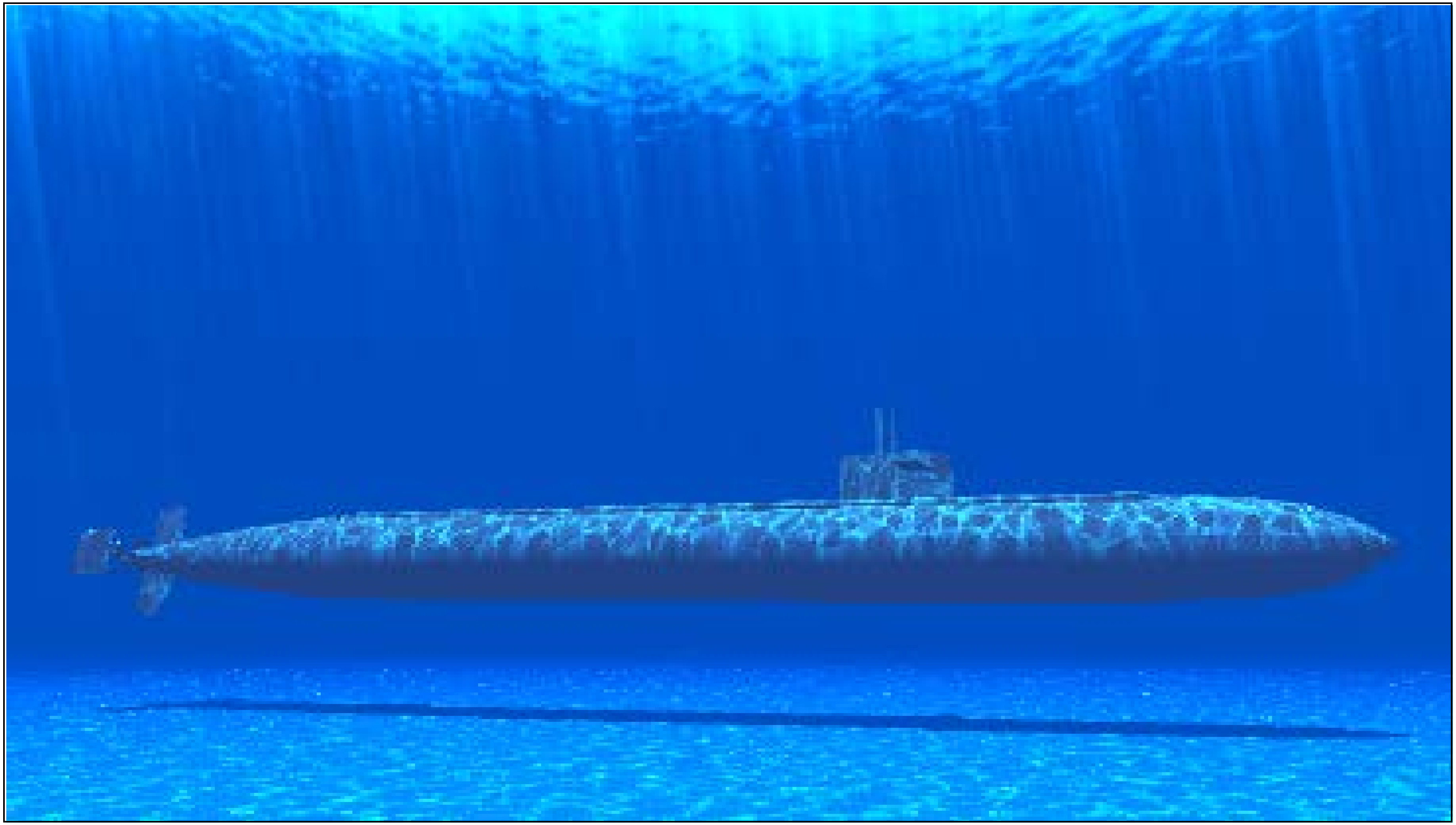



HENRIK WANN JENSEN 1995

HENRIK WANN JENSEN 1995

Looking at Water

- Light is reflected and refracted at the same time
- There is a light pattern on the ground (Caustics)

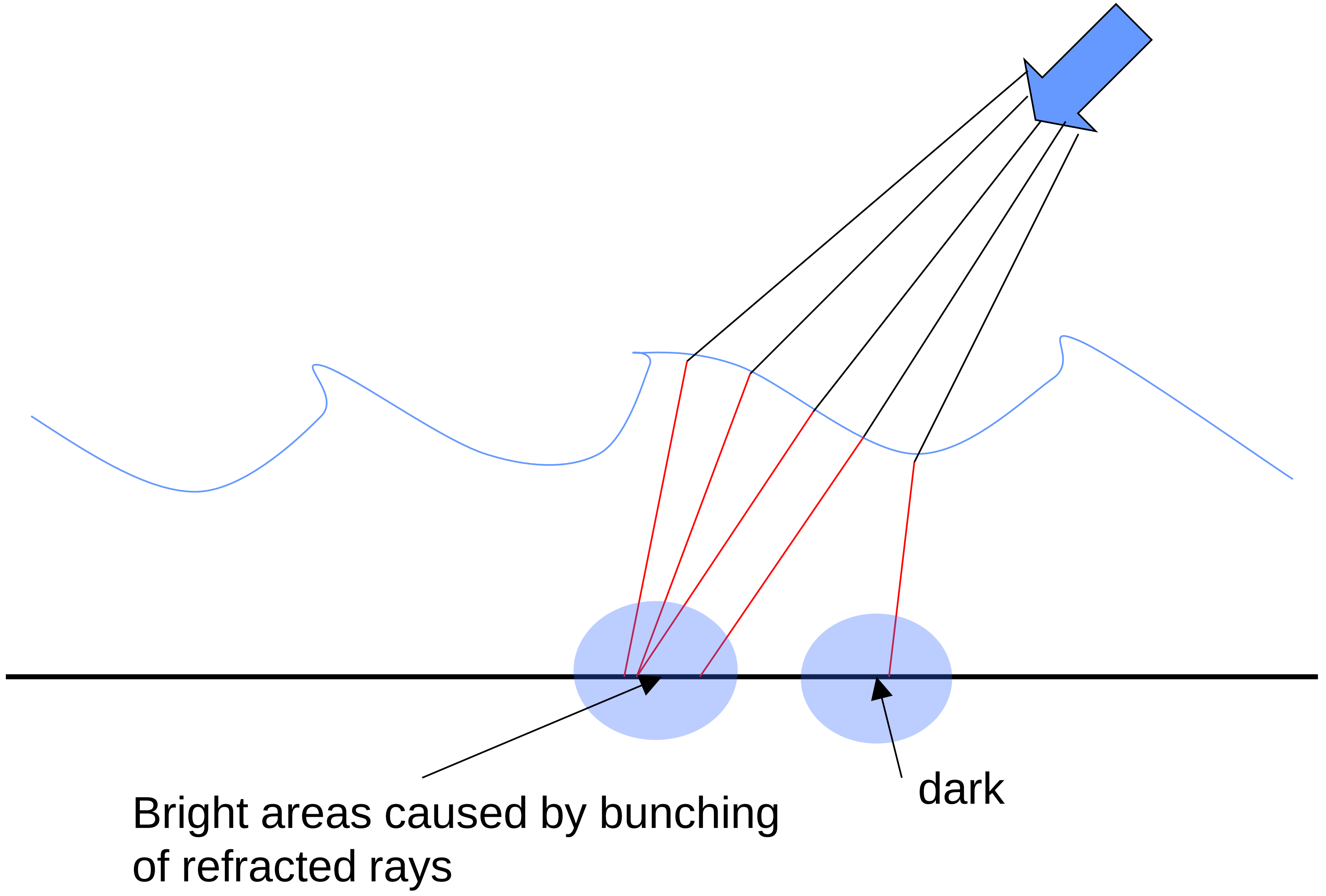
- Shafts of light and caustics:
  - ***http://nis-lab.is.s.u-tokyo.ac.jp/~nis/cdrom/pg/pg2001_iwa.pdf***



Caustics by Refraction

- Light is refracted by the water surface
- Some spots are stronger illuminated then others

Light rays through a water surface

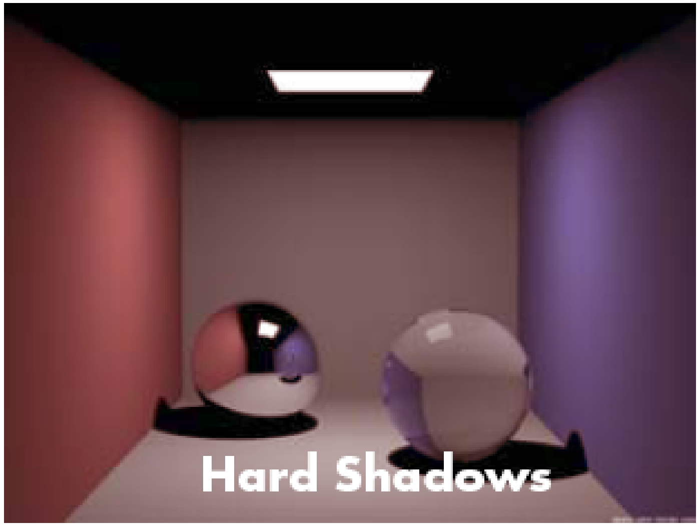


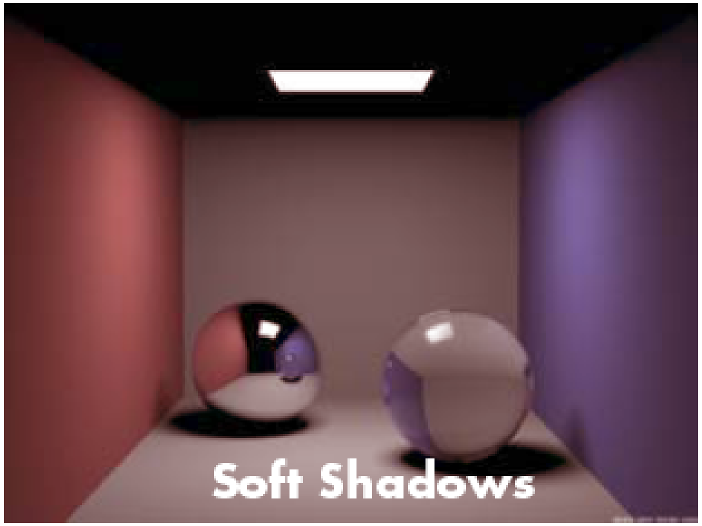
Lacemaker's Refracting Condensers (1800s)

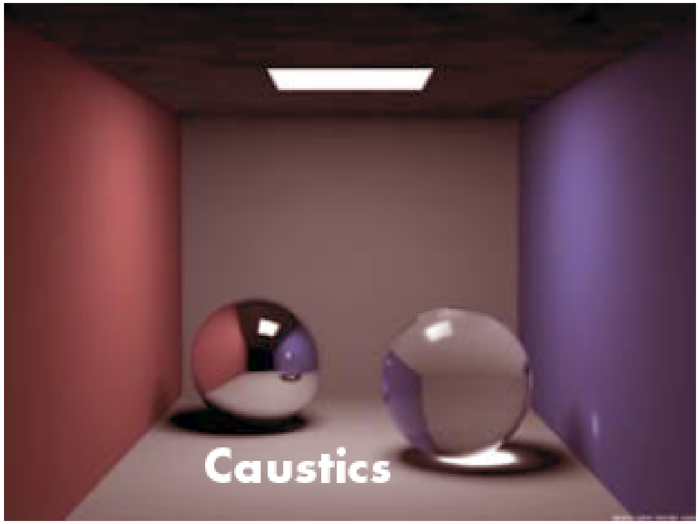
Figure 1

Water-filled glass spheres to focus or condense candlelight onto small areas

Lighting Effects



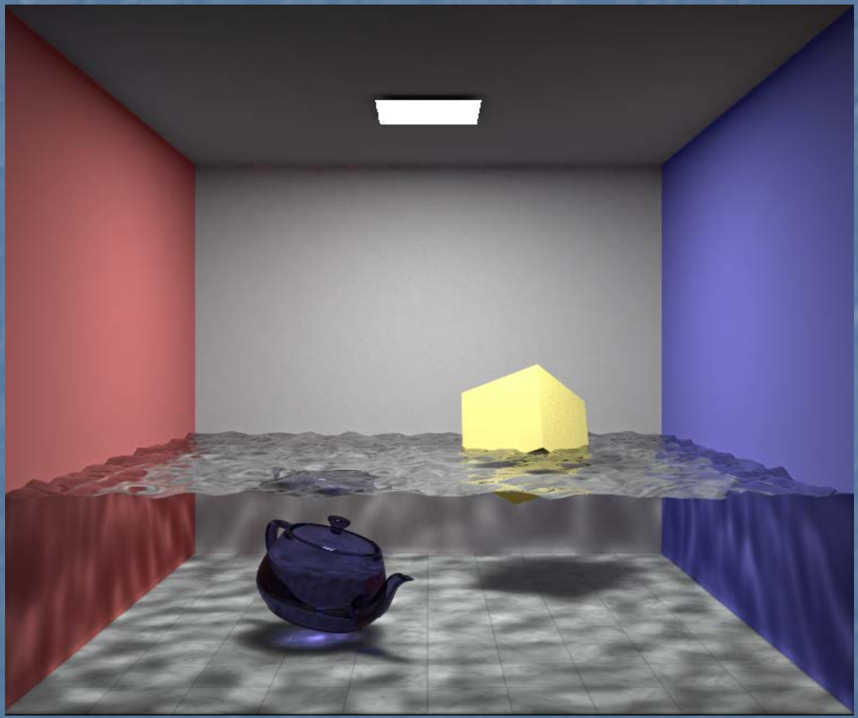


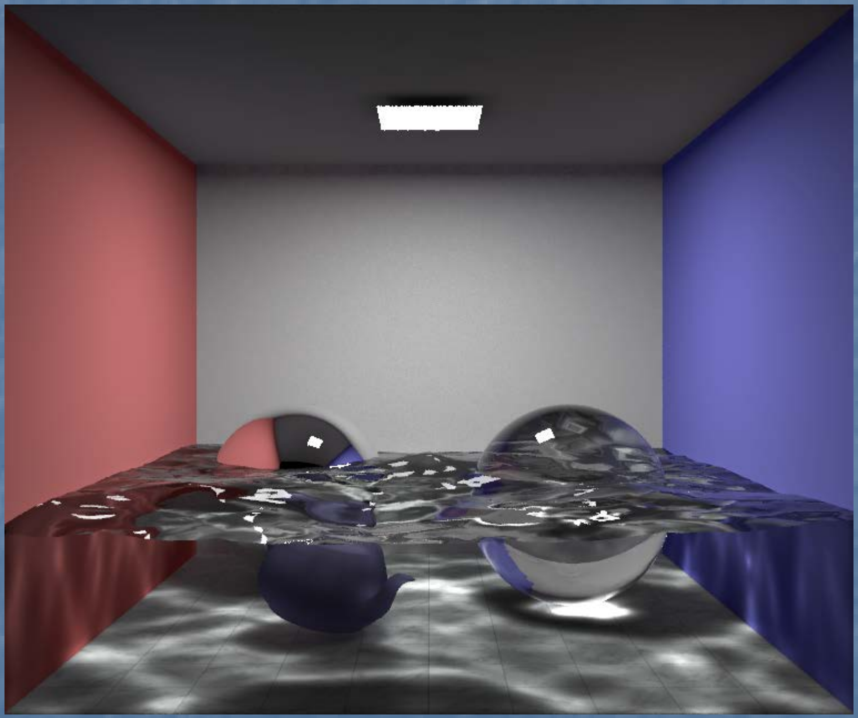


Graphics Definition

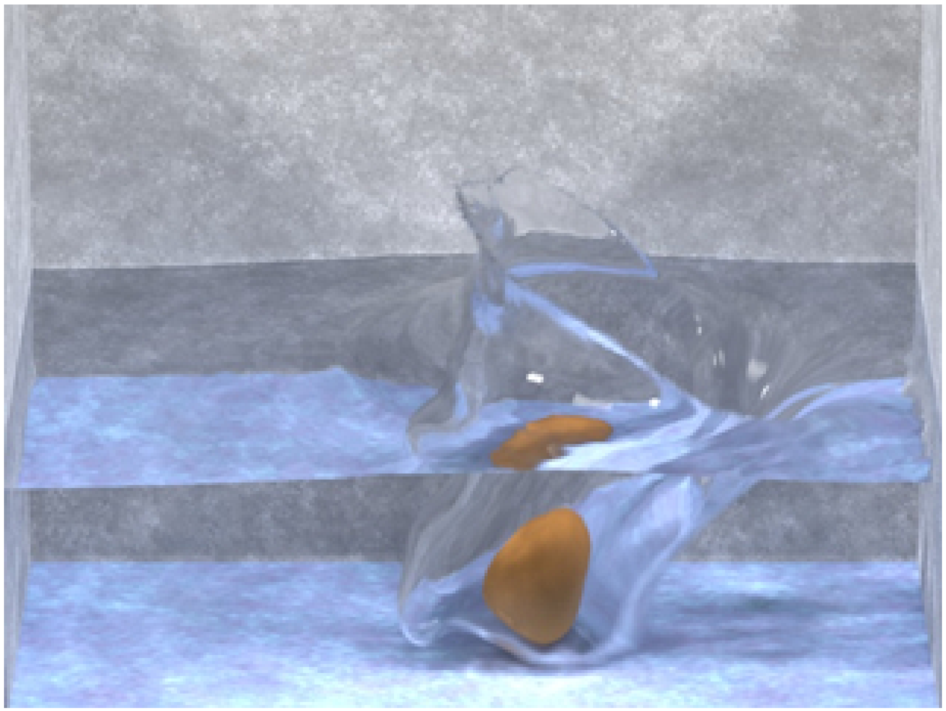
- Create nice pictures with translucent objects and render nice effects on diffuse surfaces.

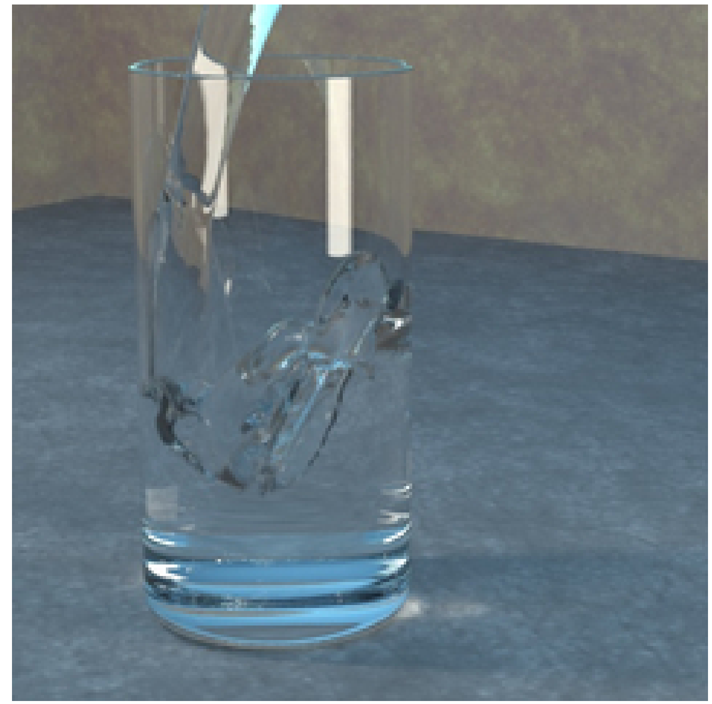
Caustics in Cornell Box



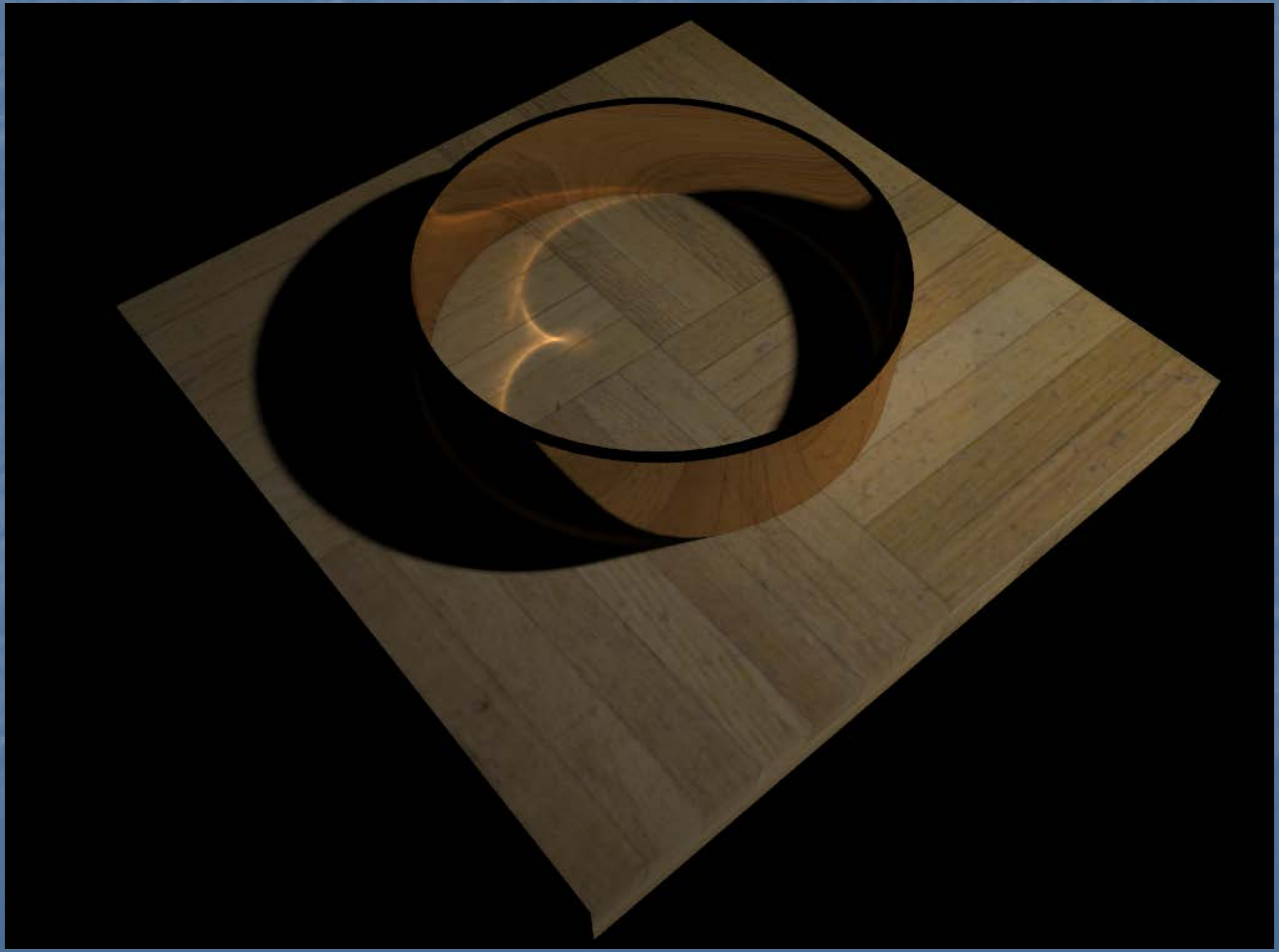


Modeling and Animating Water Surfaces





Caustics by Reflections



Reflections and Caustics : Catadioptric Imaging

+

Refractions/Reflections and Caustics: Photon Mapping

Lecture #16

Thanks to Henrik Jensen, John Hart, Ron Fedkiw, Pat Hanrahan, Rahul Swaminathan, Ko Nishino