Optics and Images

Lenses and Mirrors

Light: Interference and Optics

I. Light as a Wave
- wave basics review
- electromagnetic radiation

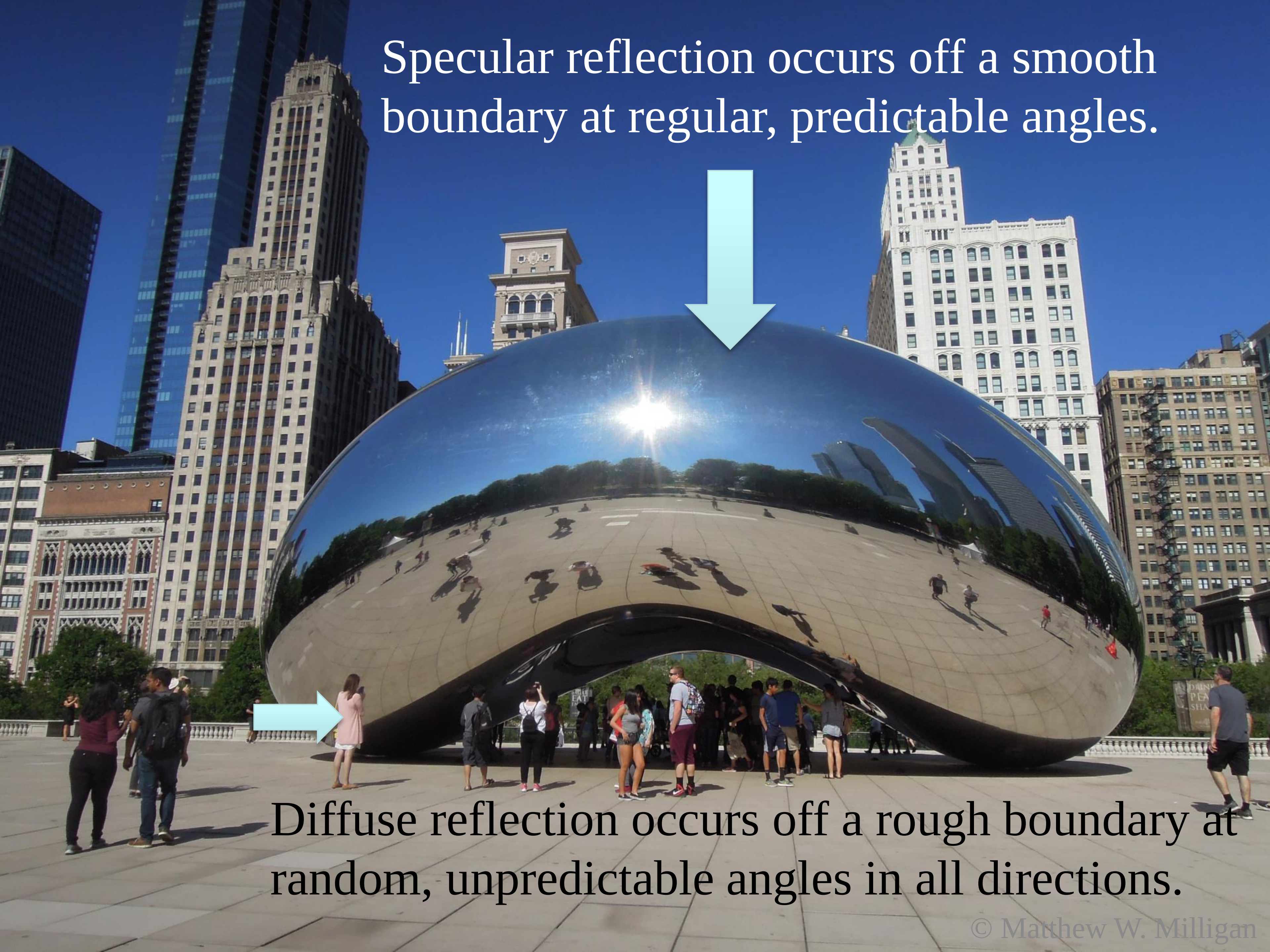
II. Diffraction and Interference
- diffraction, Huygen's principle
- superposition, interference
- standing waves, slits & gratings

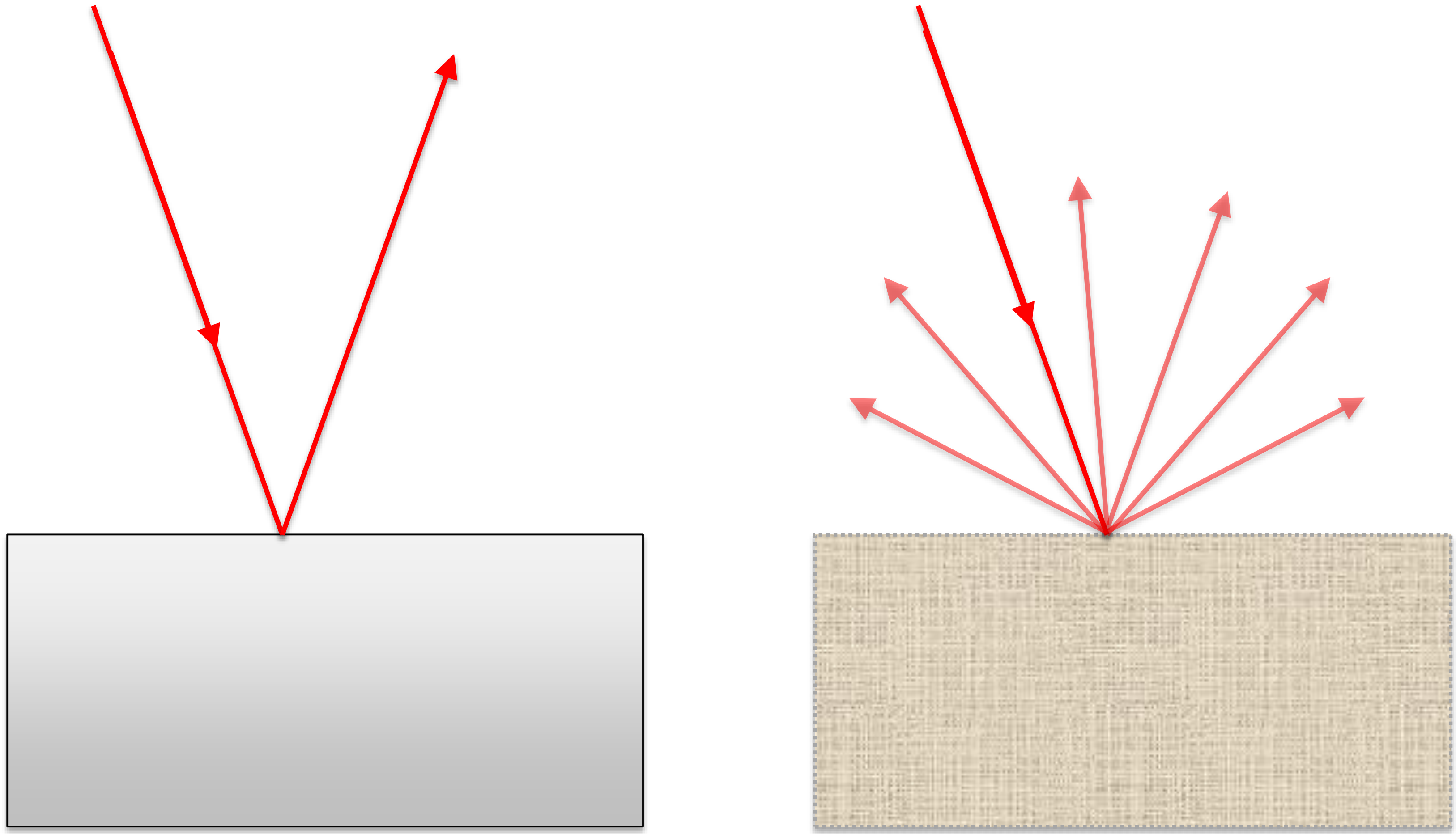
III. Geometric Optics
- **reflection, refraction, Snell's Law**
- **images, lenses, and mirrors**

	The student will be able to:	HW:
1	Model light and other types of electromagnetic radiation as a transverse wave of electric and magnetic fields and analyze graphs and/or functions to solve related problems and explain related phenomena such as polarization, absorption, production, intensity, etc.	✓ 1 – 5
2	Model diffraction and interference of light involving slits or gratings by Huygen's principle and analyze and solve problems relating geometry of openings to patterns of interference.	✓ 6 – 18
3	State and apply laws of reflection and refraction, Snell's Law, and solve related problems and/or describe qualitatively the phenomena of absorption, transmission, and reflection of light undergoing a change in medium.	19 – 25
4	Apply the ray model of light to explain and analyze formation of real and virtual images by plane, concave, and convex mirrors and solve related problems involving object and image distance, magnification, focal length and/or radius of curvature.	26 – 31
5	Apply the ray model of light to explain and analyze formation of real and virtual images by converging or diverging thin lenses and solve related problems involving object and image distance, magnification, focal length and/or radius of curvature.	32 – 36

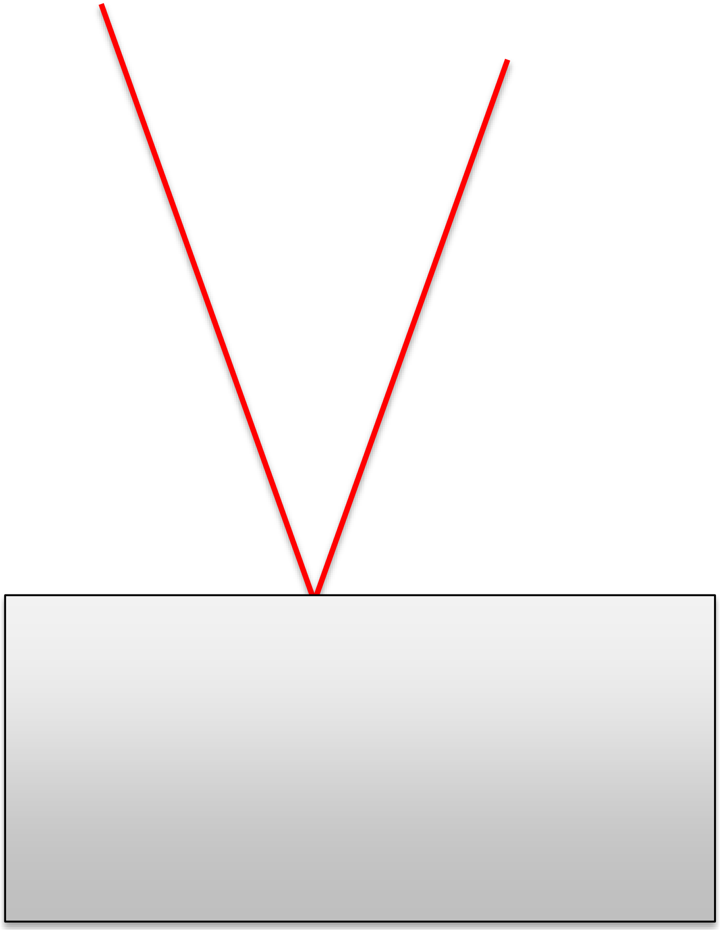
EMR – Media Boundaries

- When light encounters a change in medium several phenomena are possible: reflection, transmission, and absorption.
- Reflection: the wave is redirected at the boundary but remains in the original medium.
- Transmission: the wave continues on at the boundary, passing into and through the new medium.
- Absorption: the wave's amplitude is reduced as energy is transferred and transformed in the new medium.


Specular reflection occurs off a smooth boundary at regular, predictable angles.
Diffuse reflection occurs off a rough boundary at random, unpredictable angles in all directions.



Specular Diffuse

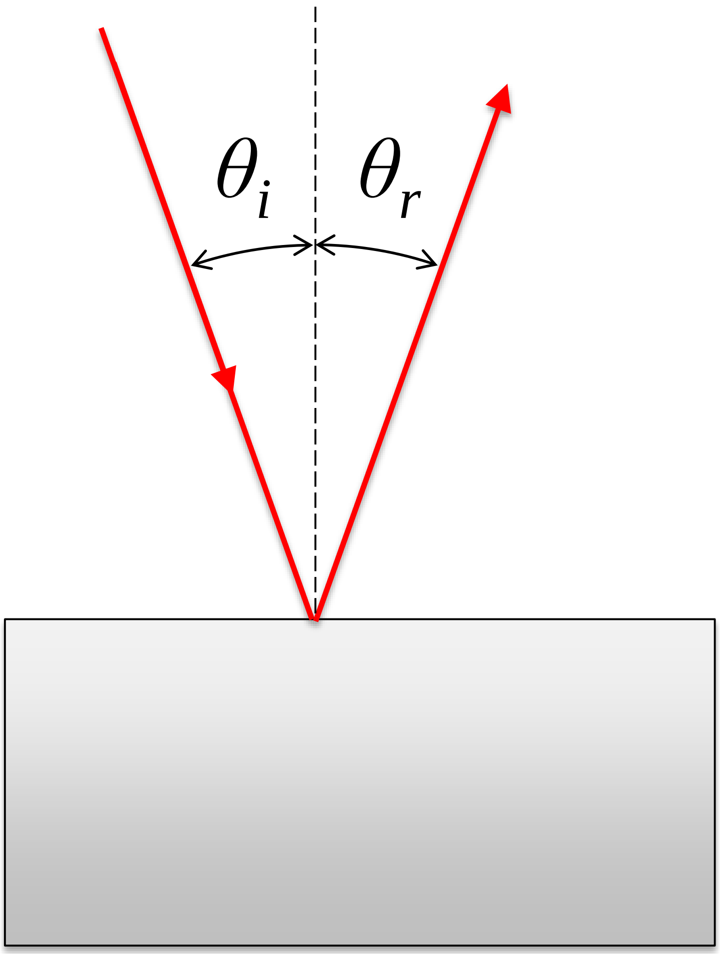


Law of Reflection

$$\theta_i = \theta_r$$

θ_i = angle of incidence
θ_r = angle of reflection

(Incident means headed toward the boundary.)



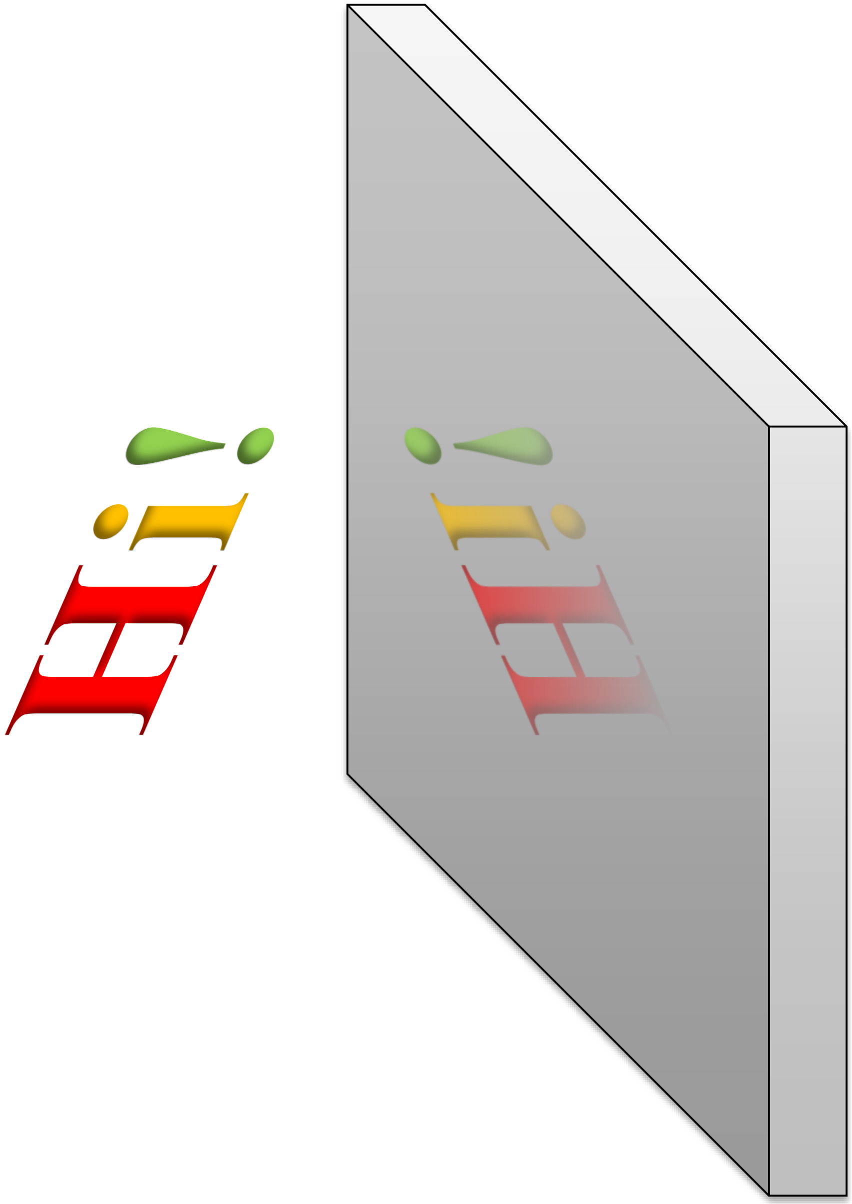
Law of Reflection

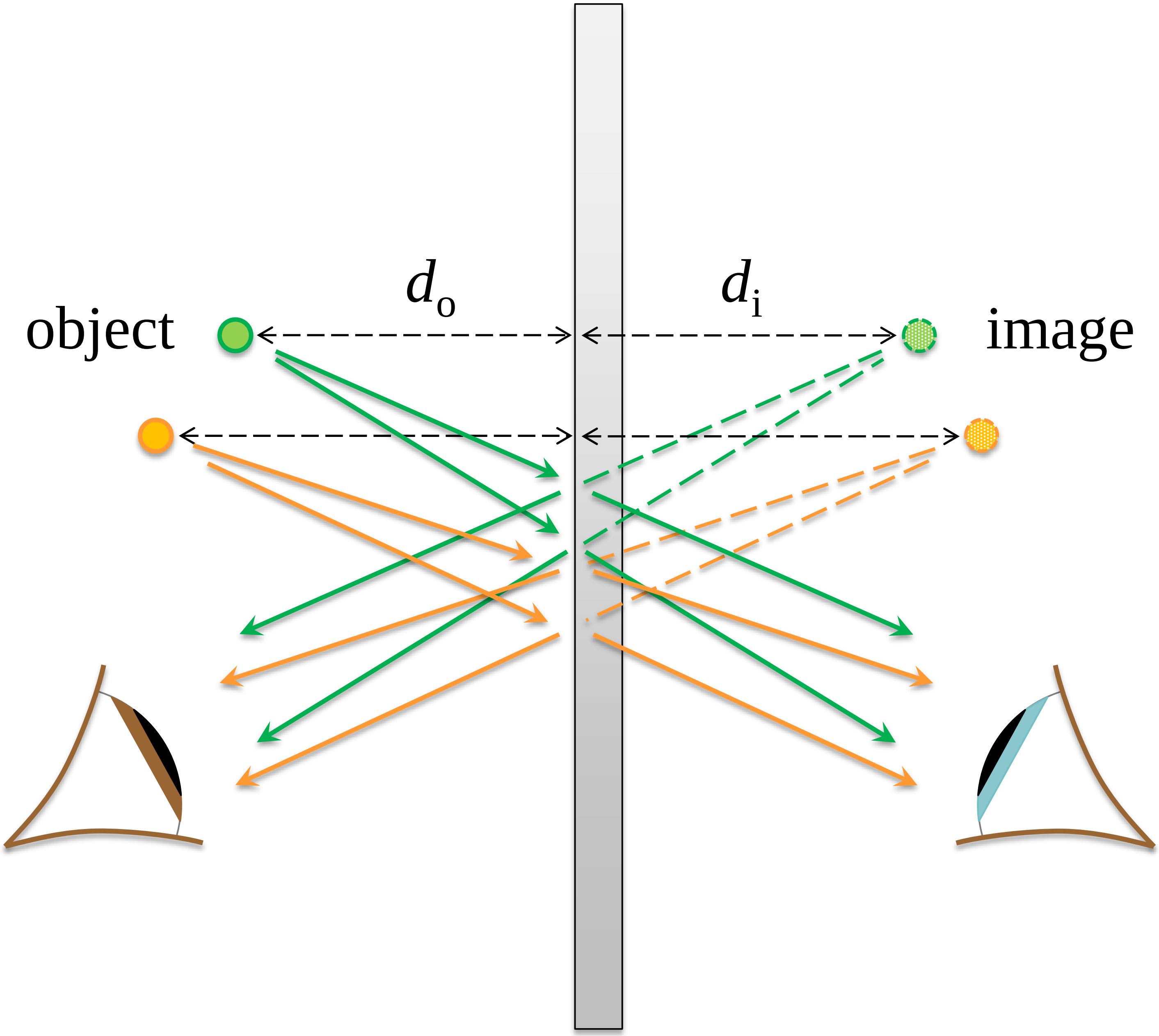
$$\theta_i = \theta_r$$

θ_i = angle of incidence
θ_r = angle of reflection

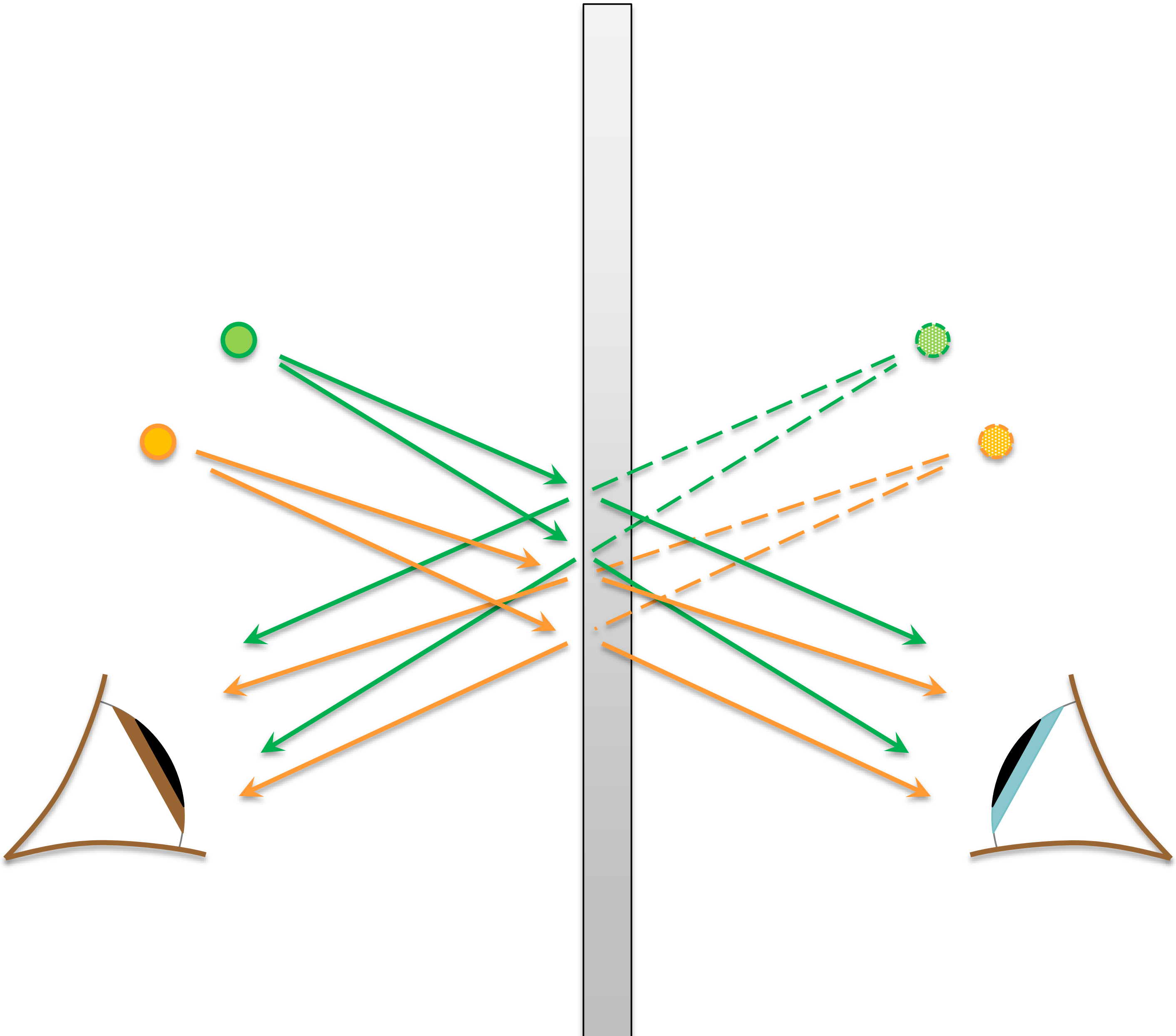
Both angles are measured relative to a line that is normal to the surface and are in the same plane.

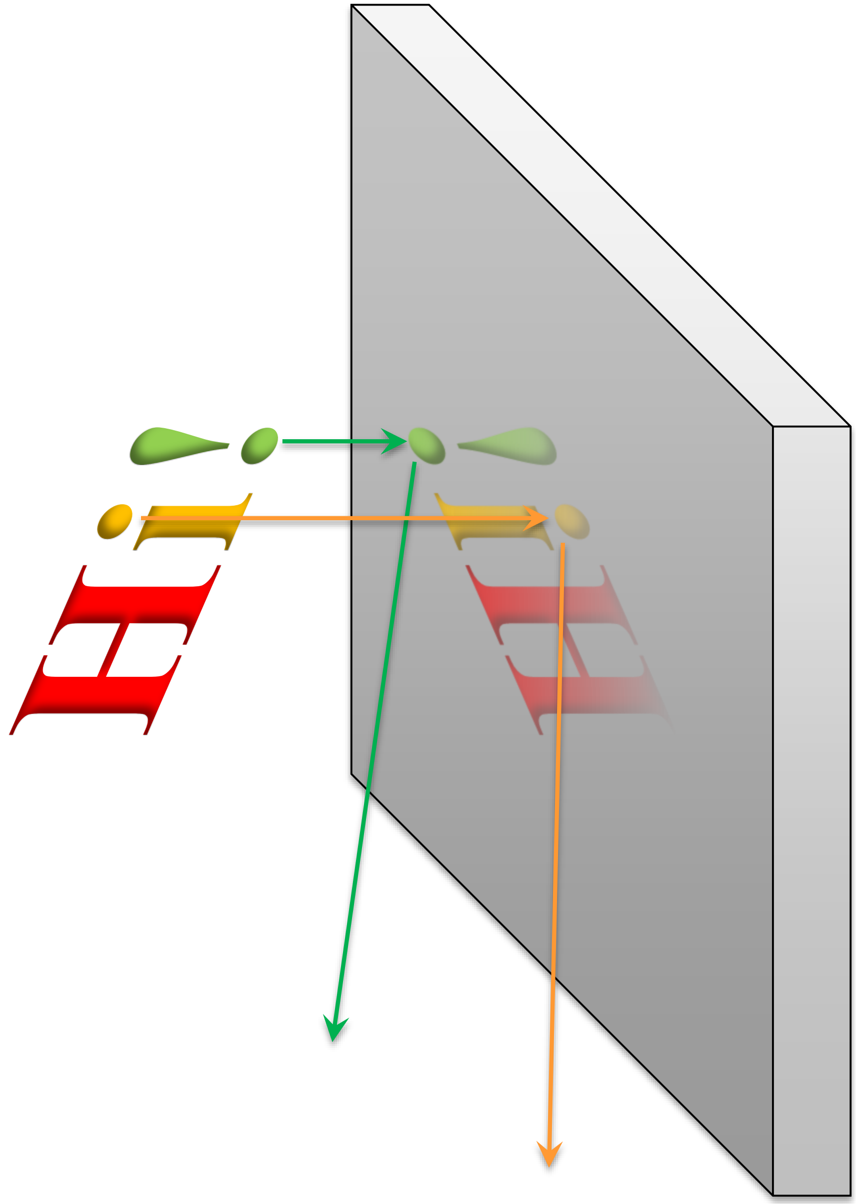
Formation of images…



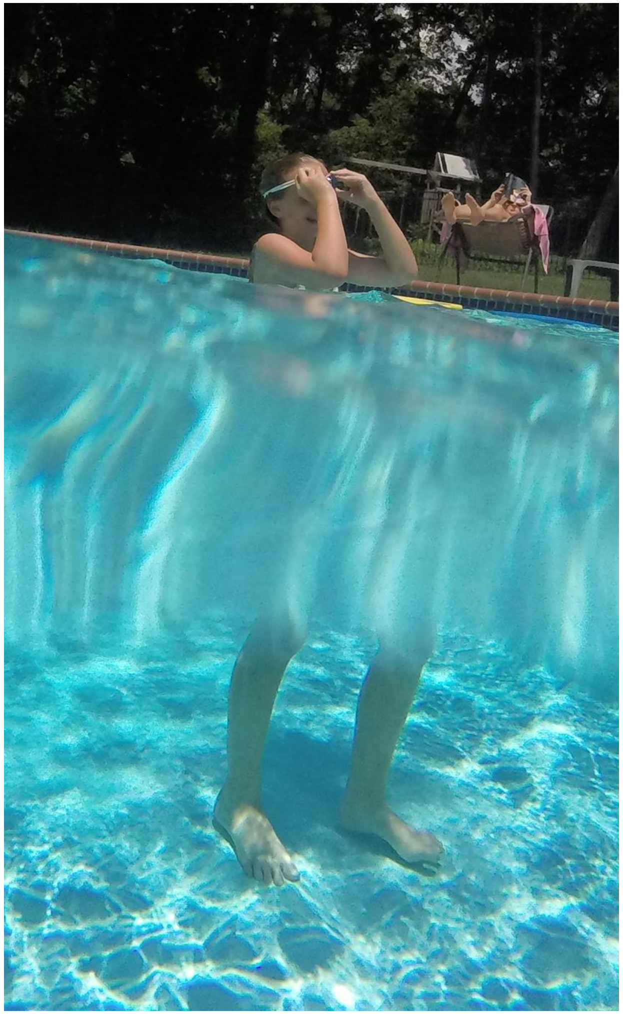


object
d_o
d_i
image



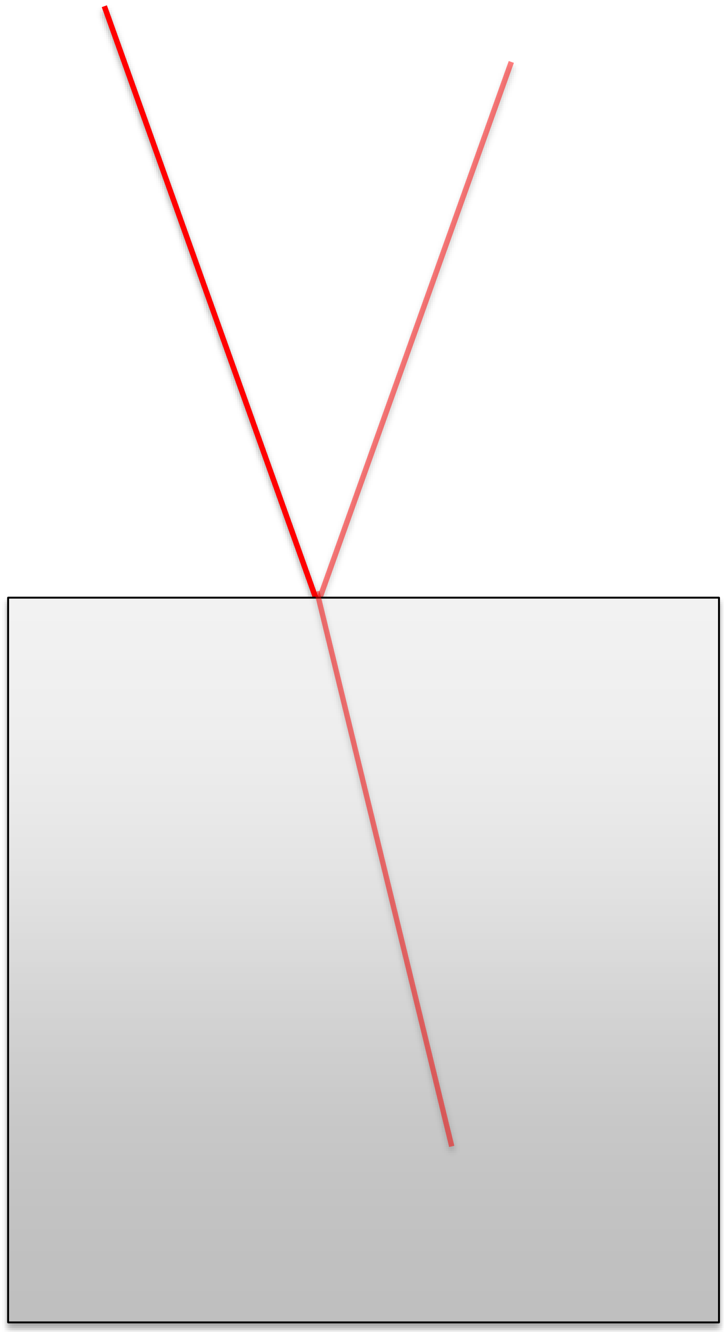


Reflection, Transmission, and Refraction



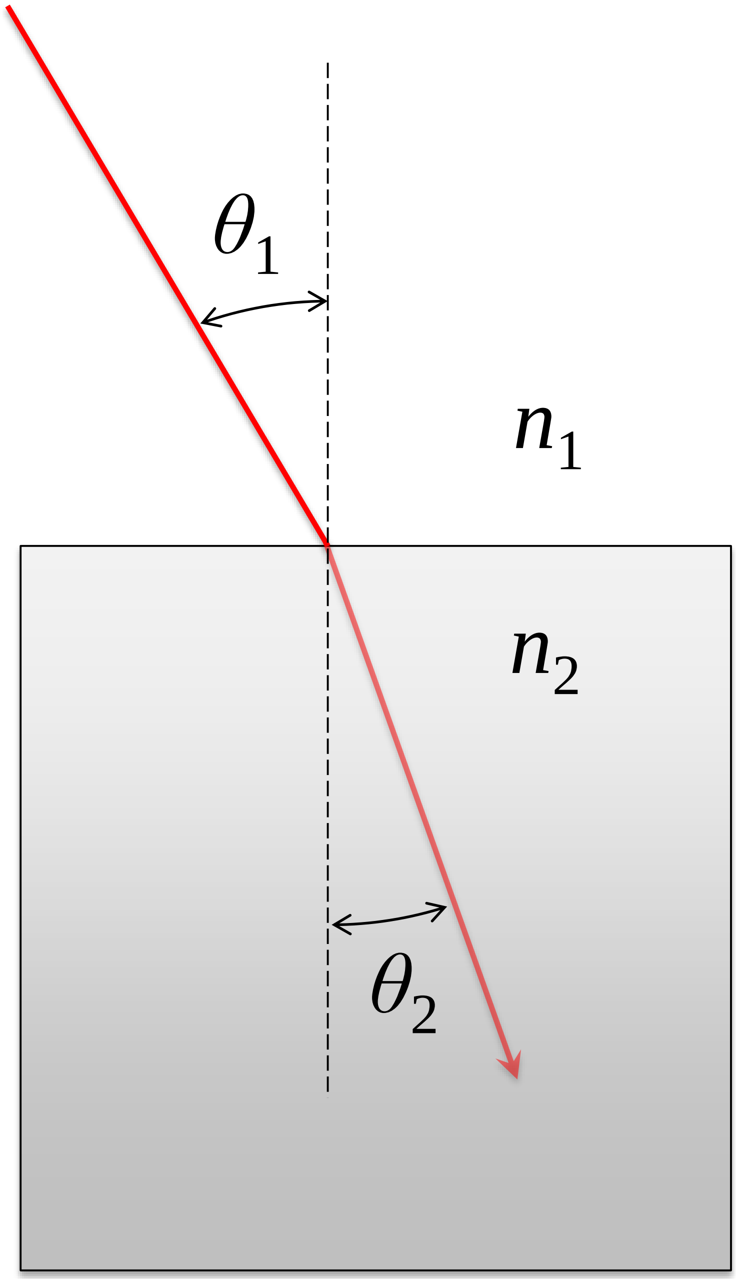
Bending of light or EMR at a boundary is called **refraction**.

Snell's Law



$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

θ_1 = angle of incidence
θ_2 = angle of refraction
n = index of refraction



Snell's Law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

θ_1 = angle of incidence
θ_2 = angle of refraction
n = index of refraction

The index of refraction is an inherent characteristic of the materials on either side of the boundary.

Medium	Index of Refraction
vacuum	1
air	1.0003
ice	1.31
water	1.33
ethyl alcohol	1.36
fused quartz	1.46
vegetable oil	1.47
acrylic, plexiglas	1.50
crown glass	1.52
flint glass	1.62
sapphire	1.77
diamond	2.42

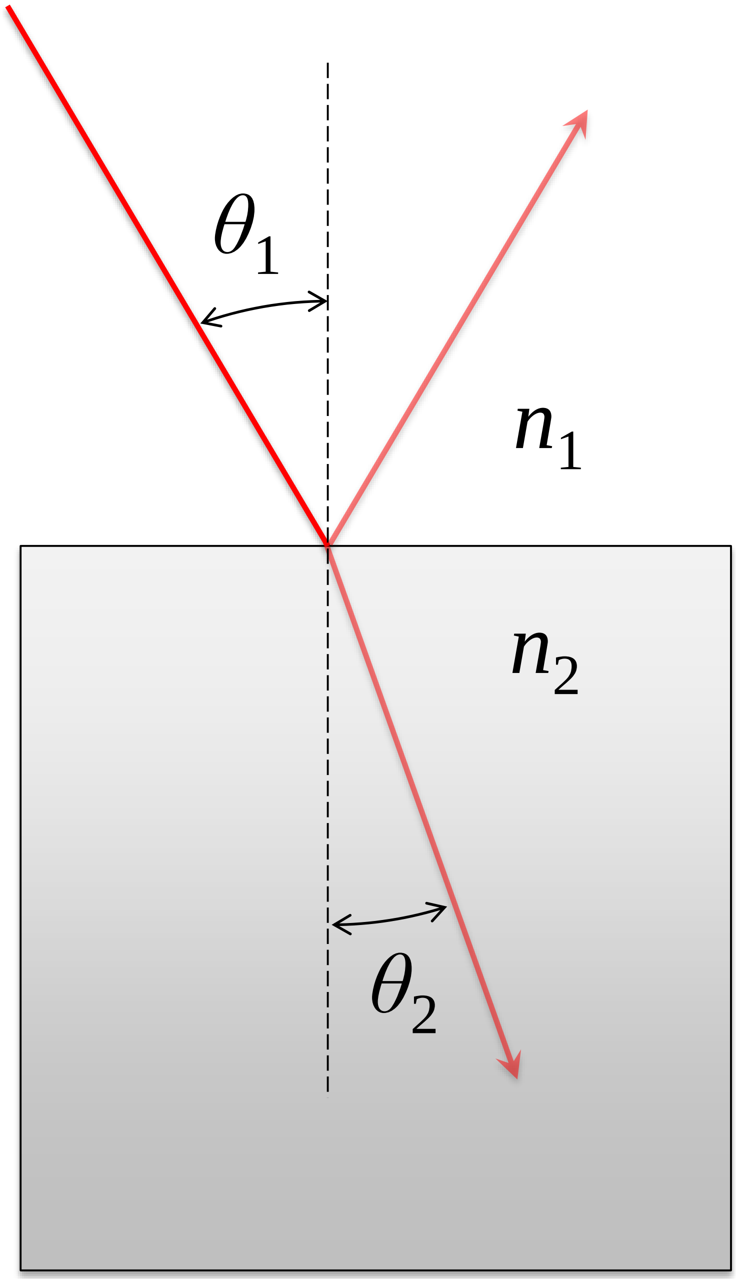
Index of Refraction

- The index of refraction is sometimes described as the "optical density" of a material. It tends to be higher in more dense materials.
- Defining $n = 1$ for a vacuum it can be shown by Huygen's principle that the index of refraction is the ratio of speed of light in a vacuum, c to that within the material, v.

$$n = \frac{c}{v}$$

- The speed of light is inversely proportional to the index of refraction.

Medium	$n = c/v$	speed (m/s)
vacuum	1	299 792 458
air	1.0003	299 700 000
ice	1.31	229 000 000
water	1.33	225 000 000
ethyl alcohol	1.36	220 000 000
fused quartz	1.46	205 000 000
vegetable oil	1.47	204 000 000
acrylic, plexiglas	1.50	200 000 000
crown glass	1.52	197 000 000
flint glass	1.62	185 000 000
sapphire	1.77	169 000 000
diamond	2.42	124 000 000

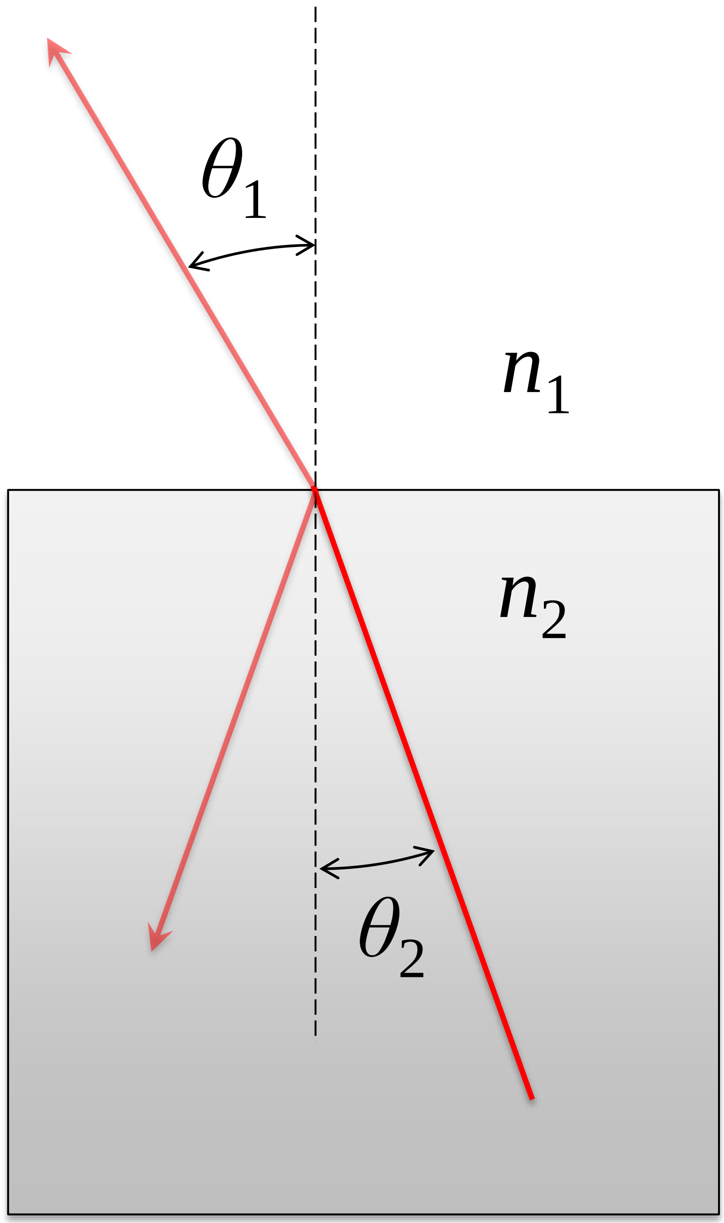


Snell's Law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

θ_1 = angle of incidence
θ_2 = angle of refraction
n = index of refraction

Typically there will be partial reflection and partial transmission.

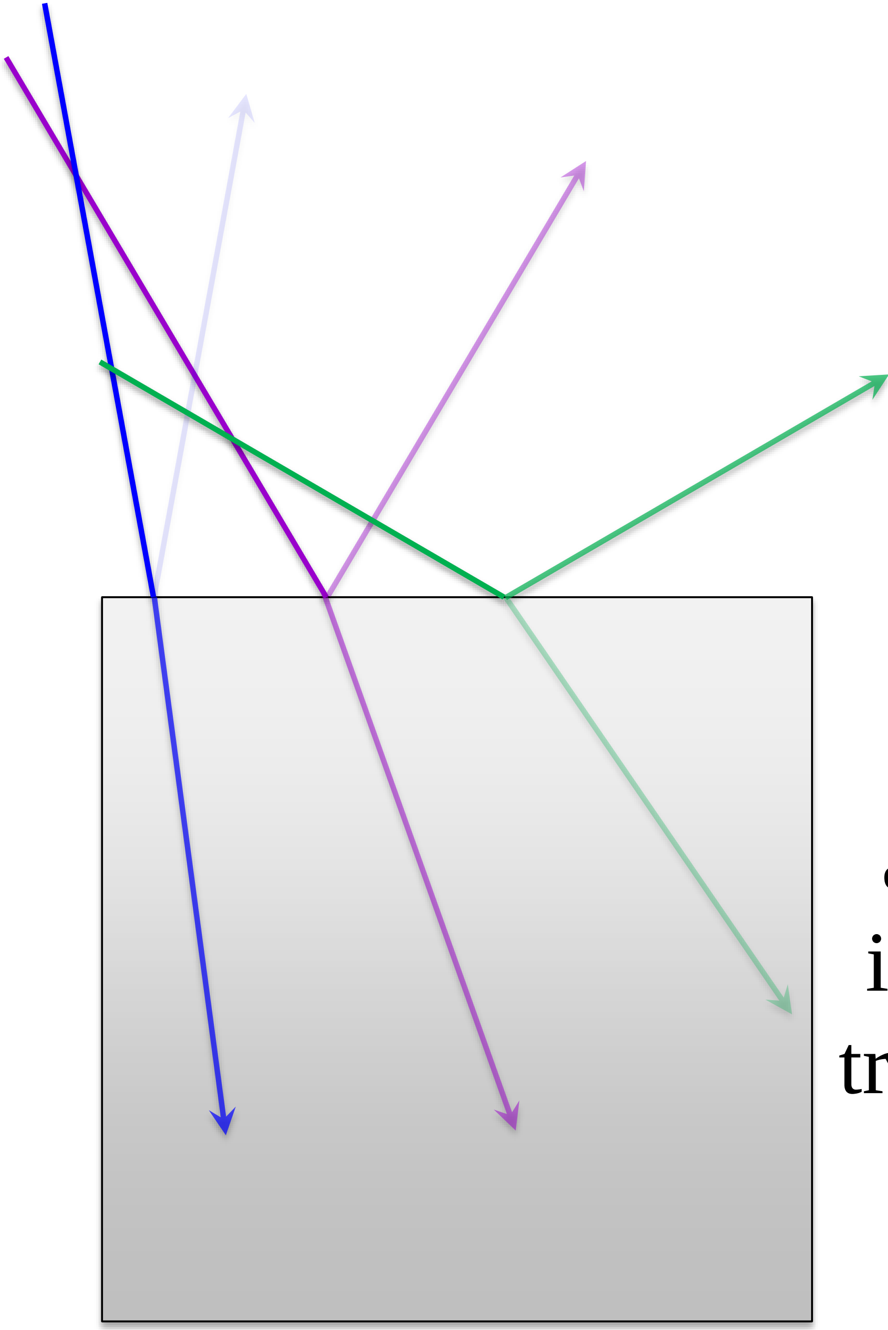


Snell's Law

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

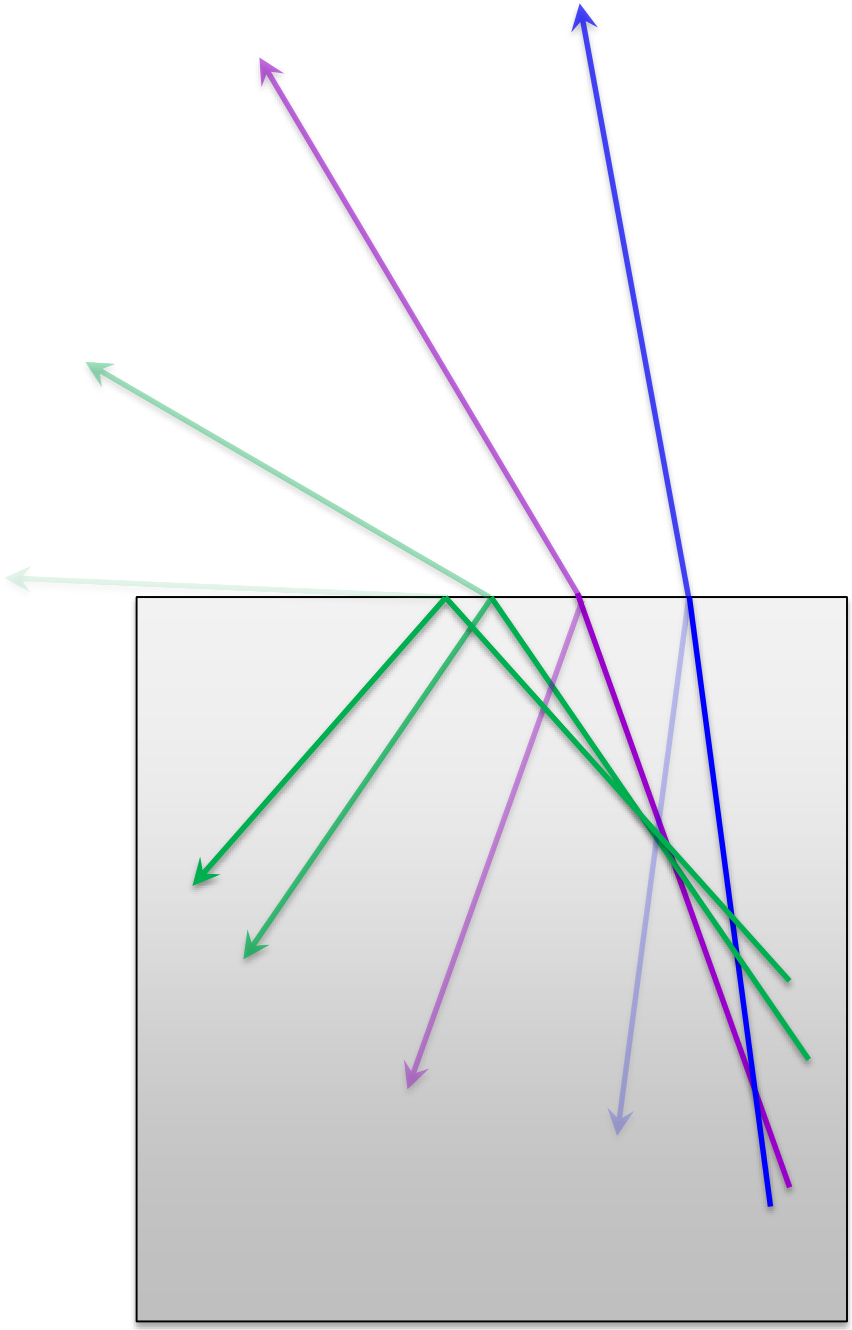
θ_1 = angle of refraction
θ_2 = angle of incidence
n = index of refraction

Typically there will be partial reflection and partial transmission.



Relative Intensity:

In general, as the angle of incidence increases, the amount of reflected energy increases and the amount of transmitted energy decreases.

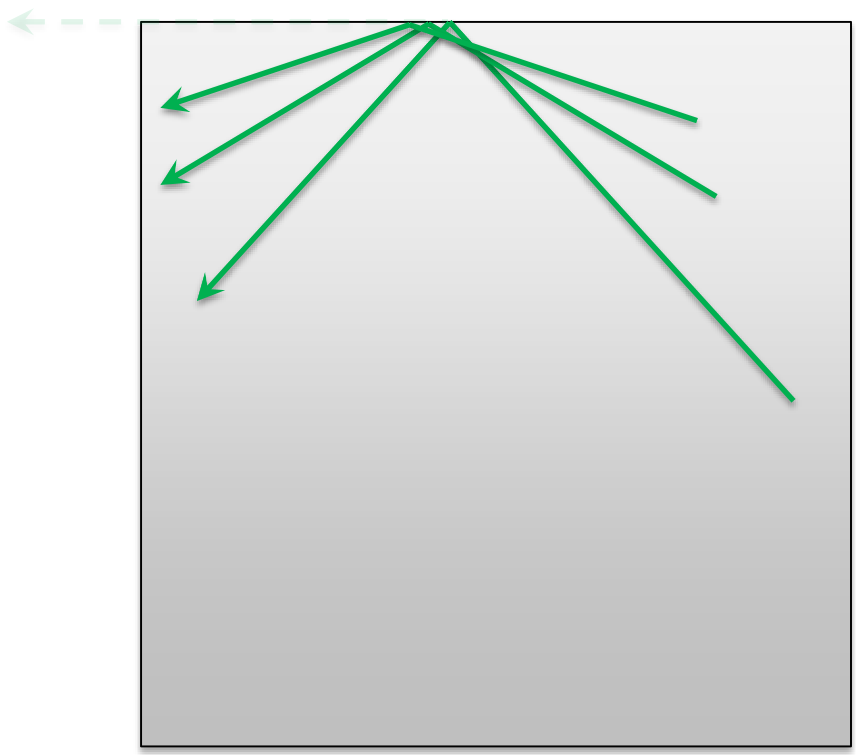


Relative Intensity:

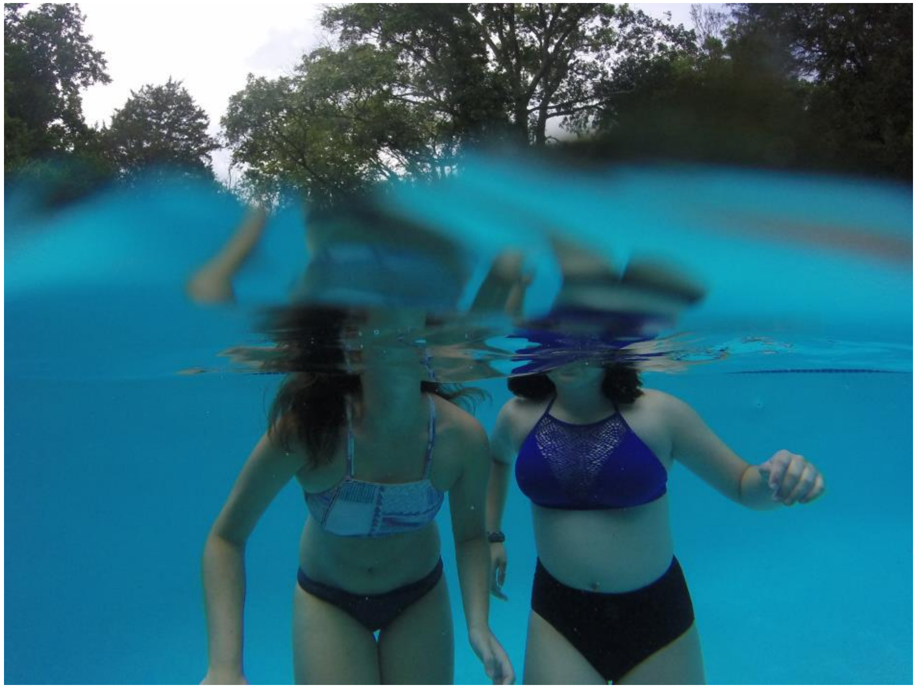
In general, as the angle of incidence increases, the amount of reflected energy increases and the amount of transmitted energy decreases.

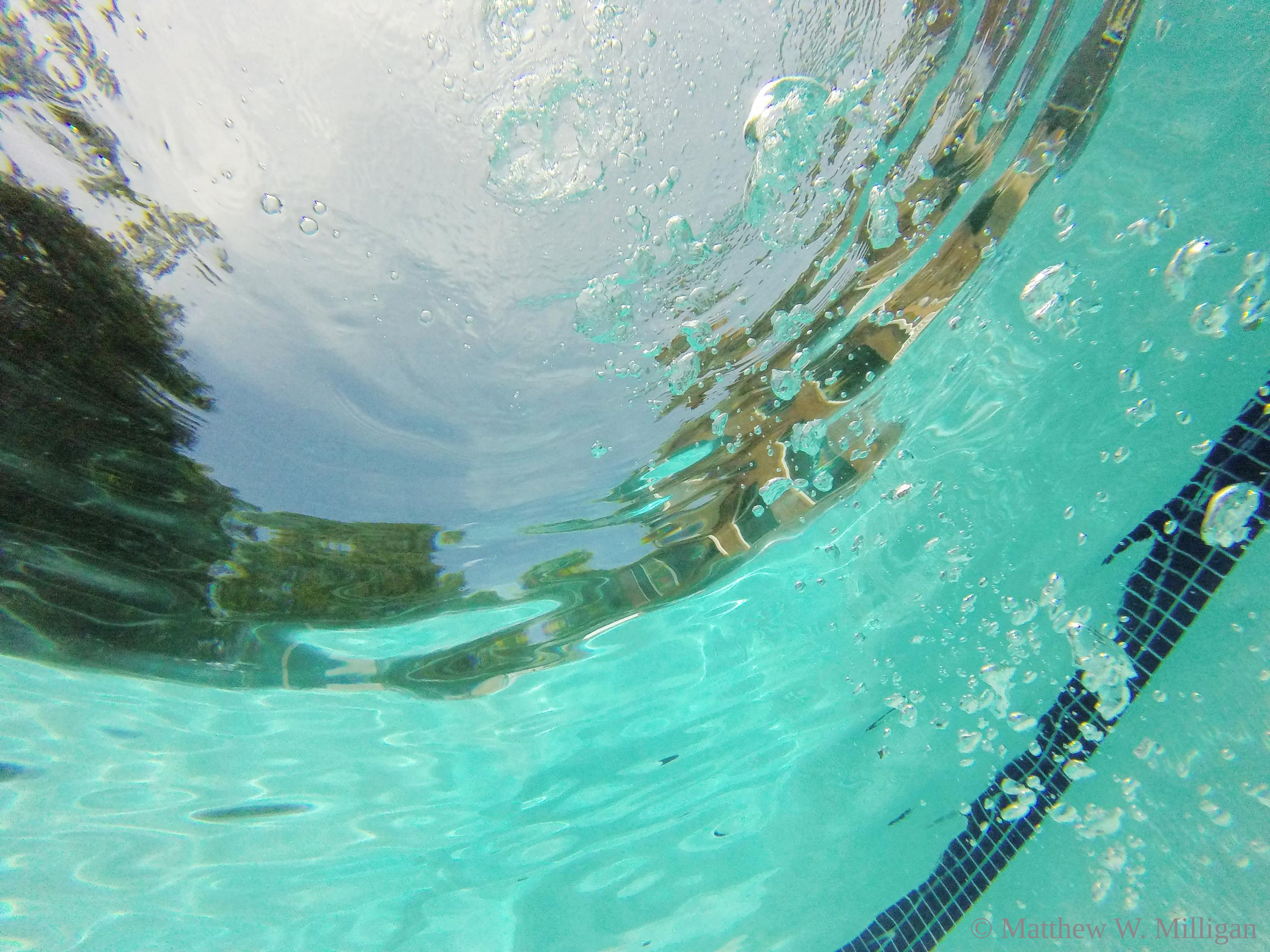
Total Internal Reflection

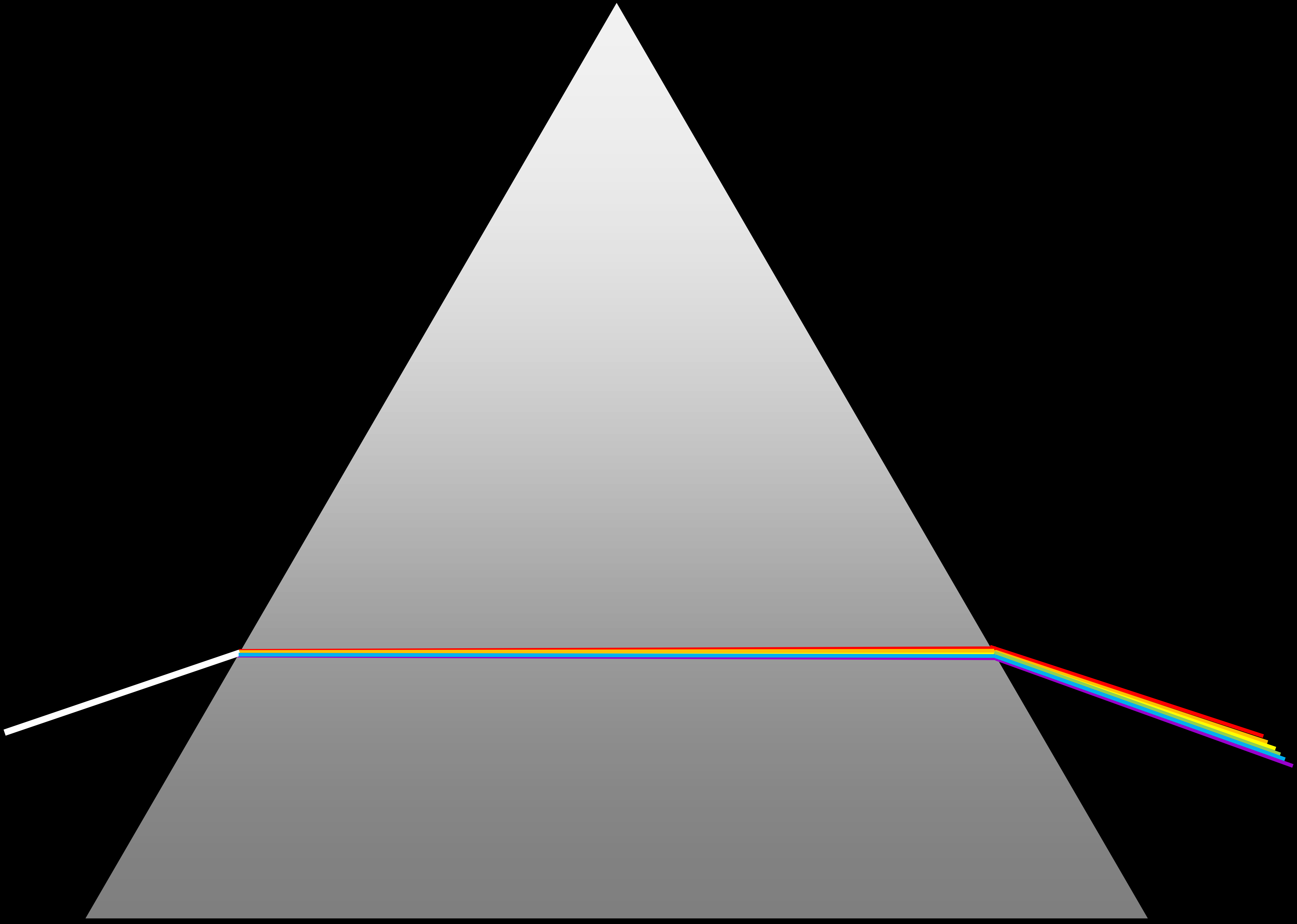
When light passes from a higher to a lower index of refraction the amount of transmitted energy drops to zero for angles of incidence greater than or equal to the "critical angle".



In this special case there is **total reflection**. The angle of refraction has no real solutions in Snell's Law for this situation.





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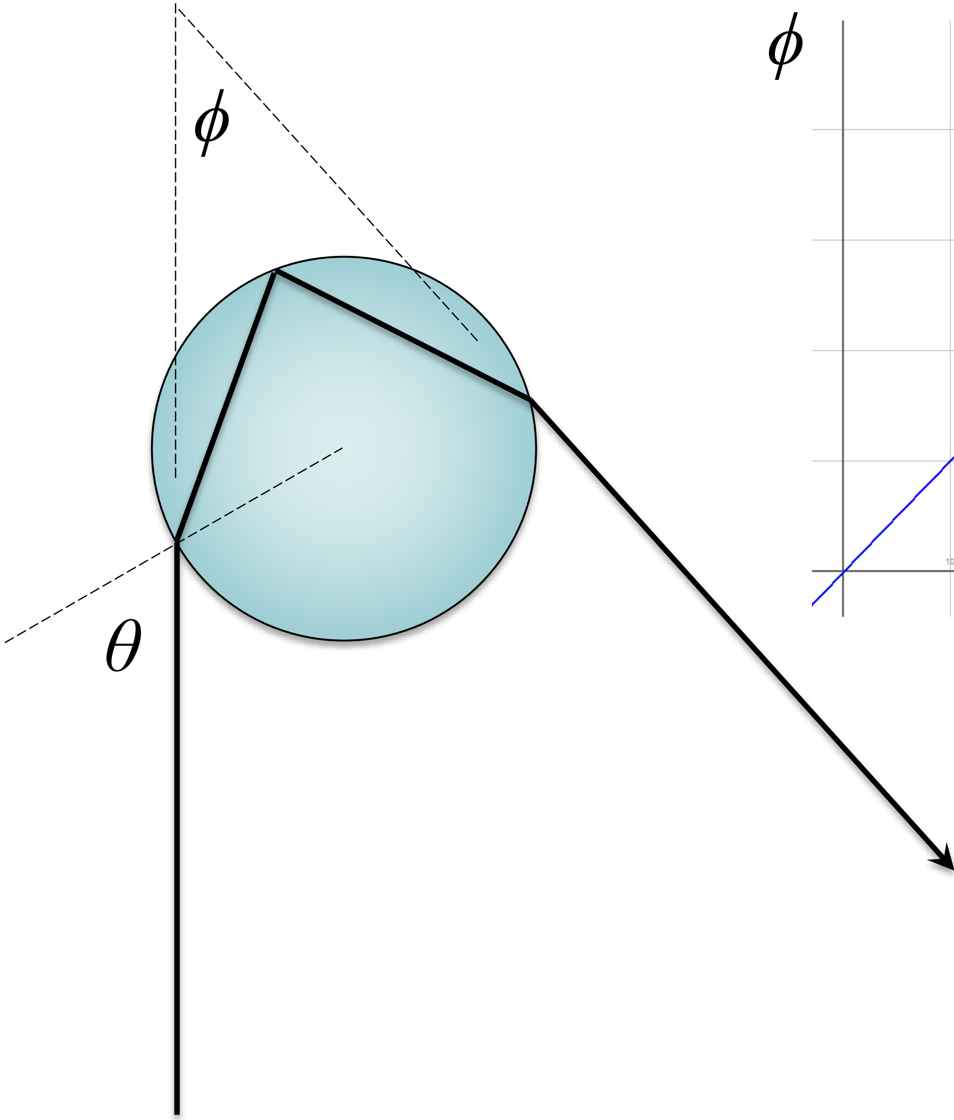
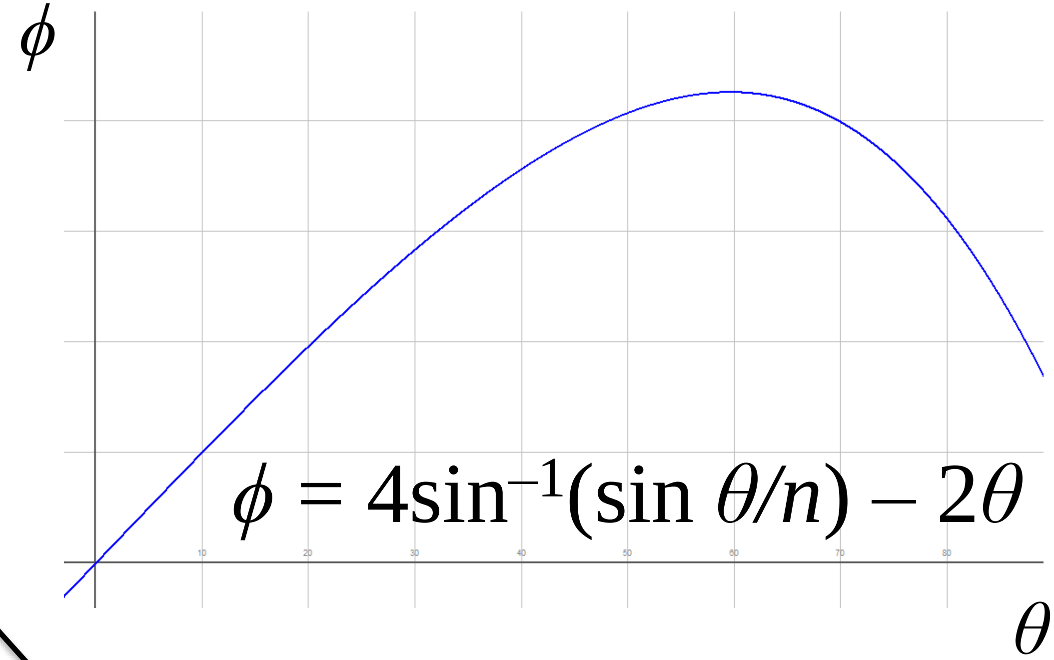
Dispersion

- The index of refraction is primarily a function of the properties of a material.
- However, the index also has a very slight dependence upon frequency and wavelength.
- The value of n increases as frequency increases and wavelength decreases. Therefore violet light refracts more than red.
- The variance of n is typically less than 1% over the range of visible light frequencies. *e.g.* for water $1.330 < n < 1.339$



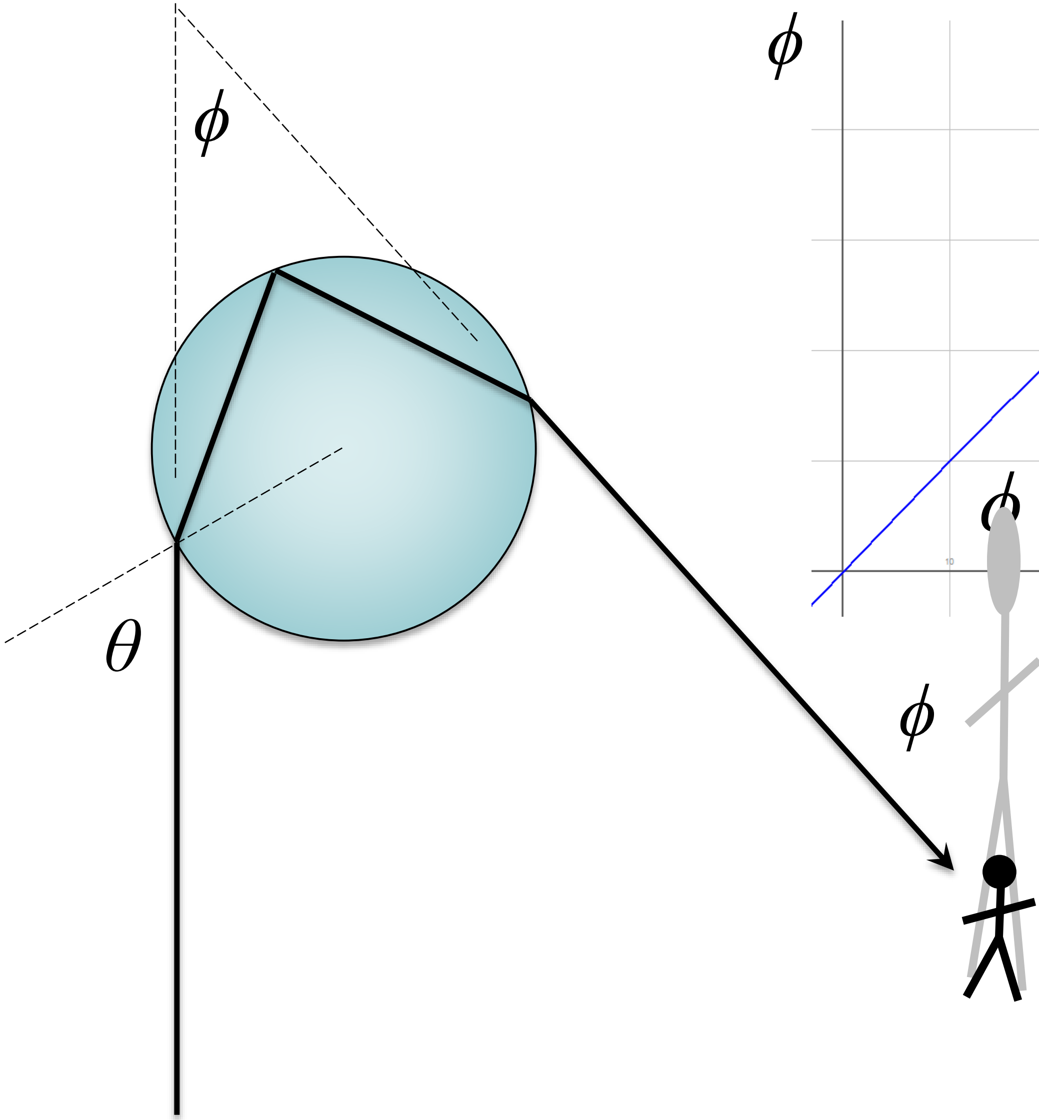


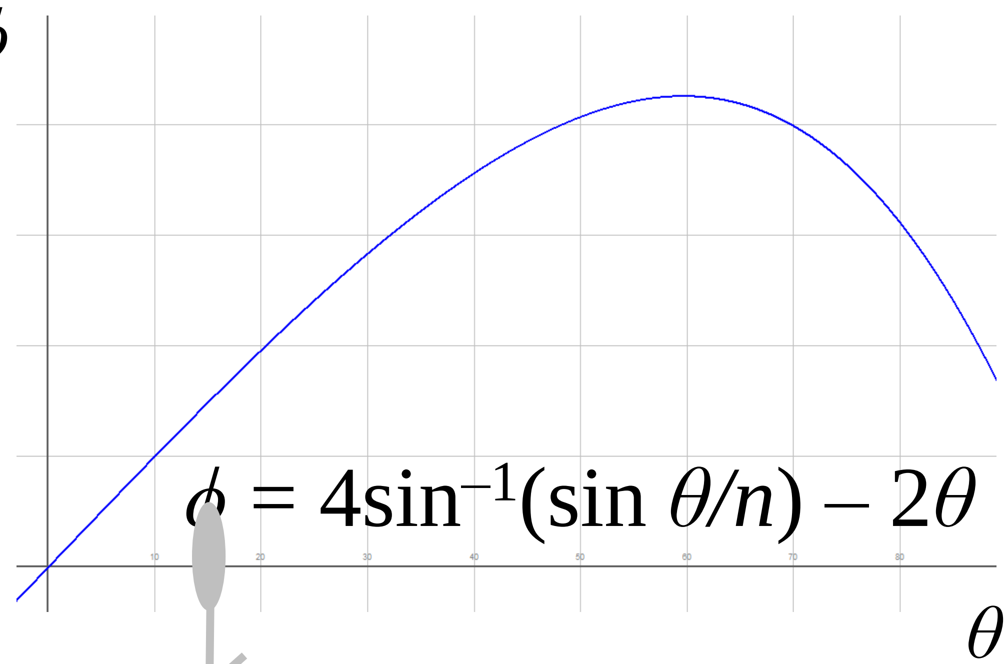
$$\phi = 4\sin^{-1}(\sin\theta/n) - 2\theta$$

(for water n = 1.33)

peak of curve:

$\phi = 42.5°$ $\theta = 59.6°$





$$\phi = 4\sin^{-1}(\sin\theta/n) - 2\theta$$

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peak of curve:

$\phi = 42.5°$ $\theta = 59.6°$

observer sees rainbow 42 degrees from the anti-solar point – light coming from raindrops at that location

width of the rainbow by previous equation is $\approx 1.3^{\circ}$, consistent with the picture radii 3.30 in and 3.45 in such that $42.5^{\circ} \cdot (3.45 - 3.3)/3.45 \approx 1.8^{\circ}$