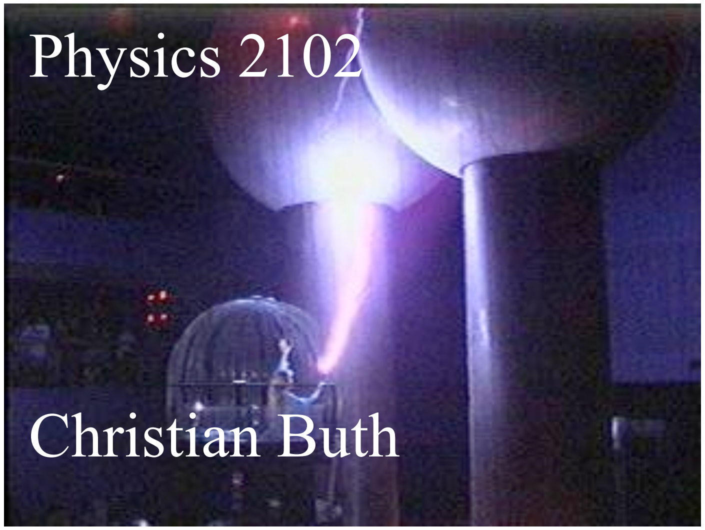


Lecture 35

Geometrical optics 1

04/15/2009

Review

- Variation of power of **spherical waves**

$$I = \frac{\text{power}}{\text{area}} = \frac{P_S}{4\pi r^2}$$

- **Radiation pressure**:

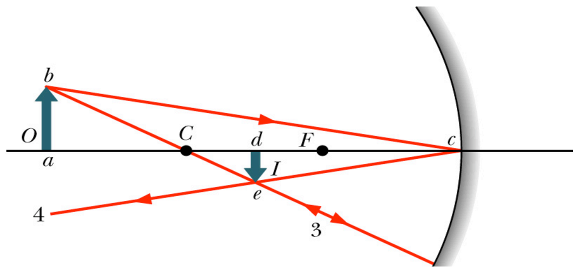
$$p_r = \frac{I}{c} \text{ (total absorption)}, \quad p_r = \frac{2I}{c} \text{ (total reflection)}$$

- **Unpolarized** light through polarizer: $I = I_0/2$
- When polarized light hits a polarizer:

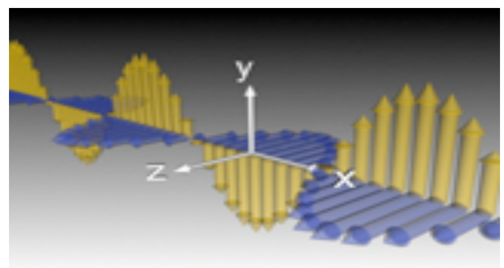
$$I = I_0 \cos^2\theta$$

Geometrical Optics

• "Geometrical" optics: light rays ("particles") that travel in straight lines.



• "Physical" optics: electromagnetic waves which have amplitude and phase that can change.

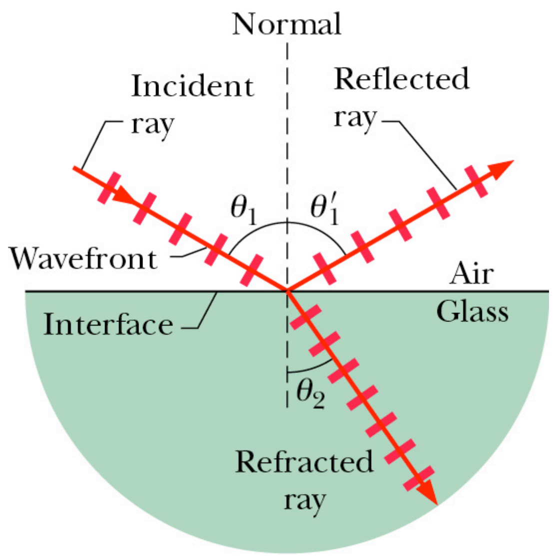


Light is BOTH a particle (photon) and a wave: wave-particle duality.

Reflection and refraction

When light finds a surface separating two media (air and water, for example), a beam gets **reflected** and another gets **refracted** (transmitted).

Law of reflection: the angle of incidence θ_1 equals the angle of reflection θ'_1.



(b)

Law of refraction: $n_2 \sin\theta_2 = n_1 \sin\theta_1$ Snell's law.

n is the index of refraction of the medium.
In vacuum, n=1. In air, n~1. In all other media, n>1.

Example

Water has n=1.33. How much does a beam incident at 45^o refracts?

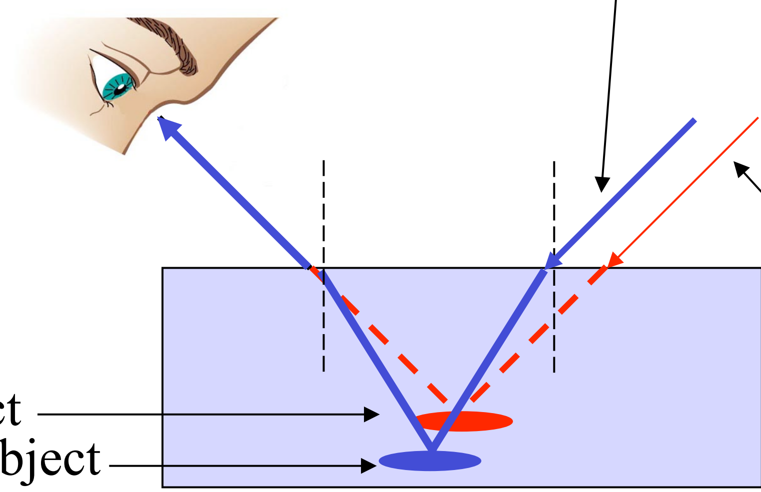
$n_2 \sin\theta_2 = n_1 \sin\theta_1$

$\sin\theta_2 = (n_1/n_2)\sin\theta_1$

$=(1/1.33)\sin 45^o$

$=0.0098$

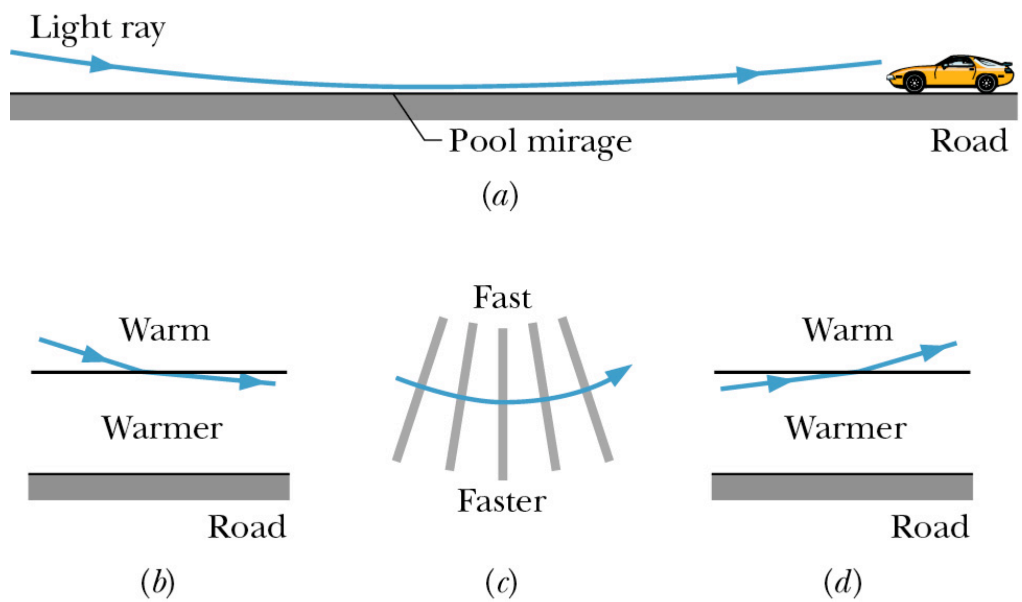
$\theta_2 = 32^o$



Example: an optical illusion

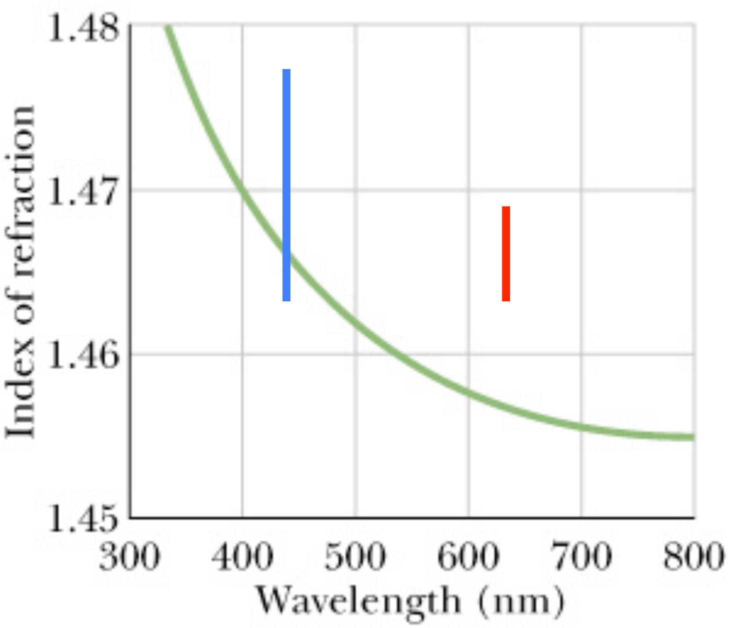
The index of refraction decreases with temperature: the light gets refracted and ends up bending upwards.

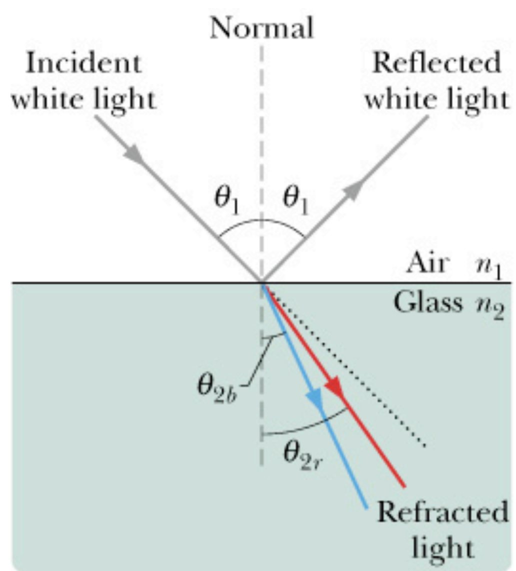
We seem to see water on the road, but in fact we are looking at the sky!



Chromatic dispersion definition

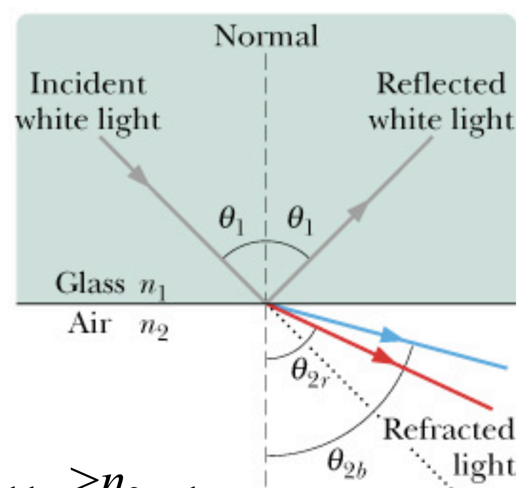
- Index of refraction depends on the **wavelength** (color) of light
- Light of different wavelengths is refracted differently → **chromatic dispersion**





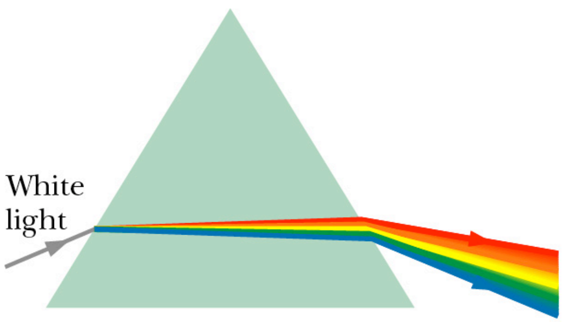
(a)

$n_{,\text{blue}} > n_{2,\text{red}}$



(b)

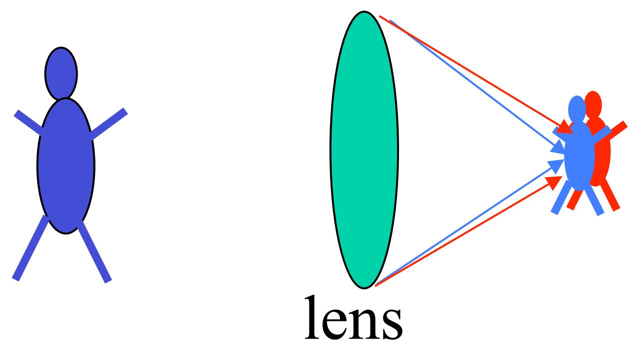
Chromatic dispersion uses



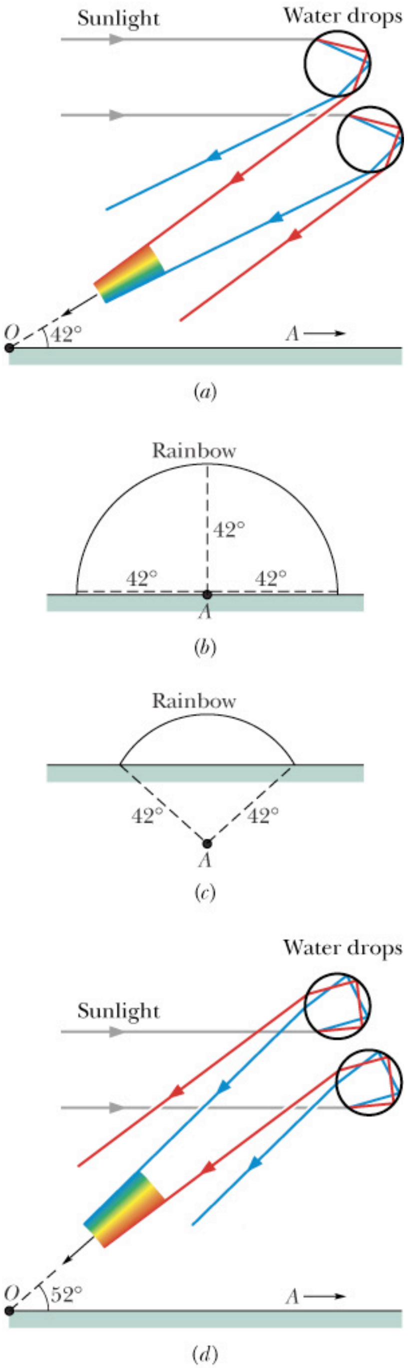
(*b*)

Chromatic dispersion can be **good** (e.g., used to analyze wavelength composition of light)

or **bad** (e.g., chromatic aberration in lenses)



Rainbows



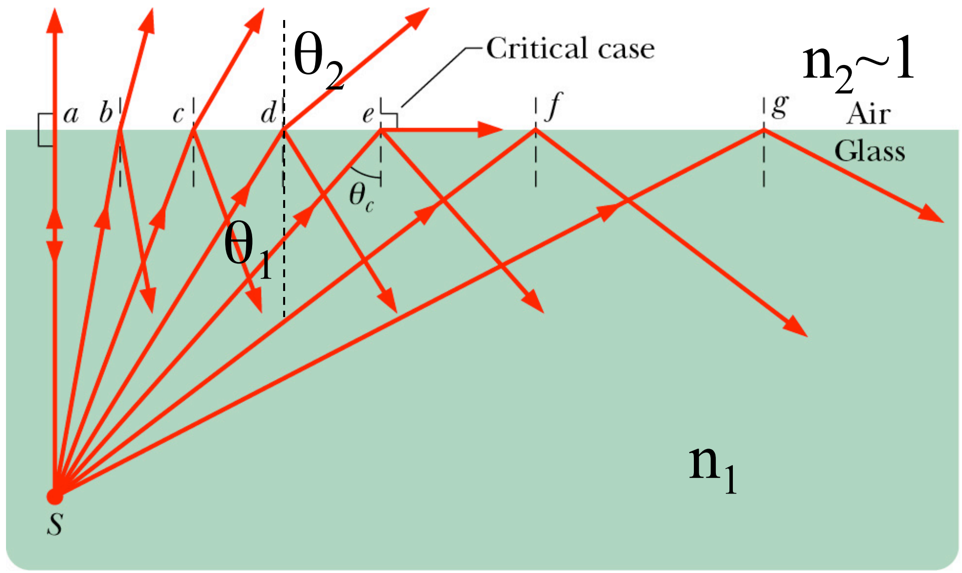
- Sunlight all visible colors; water is **dispersive**
- Sunlight is **refracted** as it enters water droplets; **reflected** off the back surface; again **refracted** as it exits the water drops
- Angles for the exiting ray depends on **color** of ray
- Blue is refracted **more strongly** than red

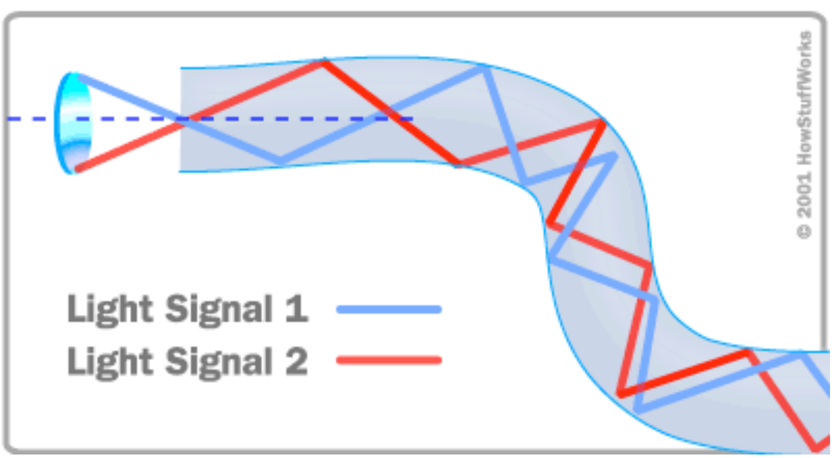
What happens for rays that reflect **twice** off the back surfaces of the droplets?

Total internal reflection

From glass to air, the law of refraction uses $n_2<n_1$, so $\theta_2>\theta_1$: it may reach 90^o or more: the ray is "reflected" instead of "refracted".

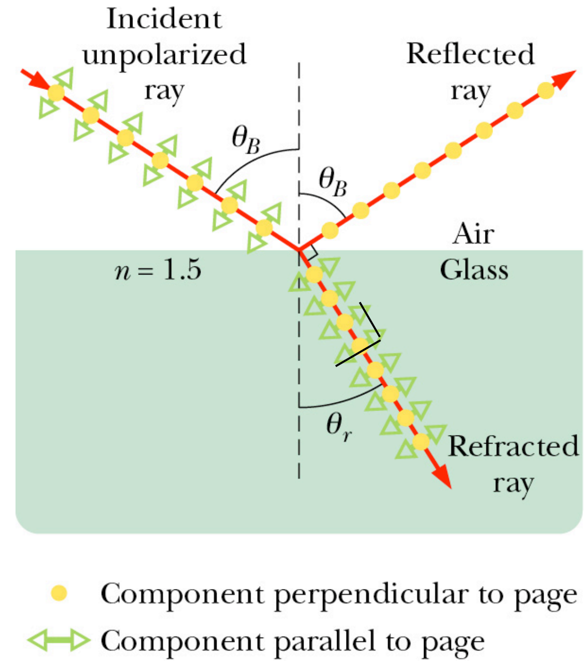
$n_2 \sin \theta_2 = n_1 \sin \theta_1$





For glass (fused quartz) n=1.46, and the critical angle is 43^o: optical fibers!

Polarization by reflection

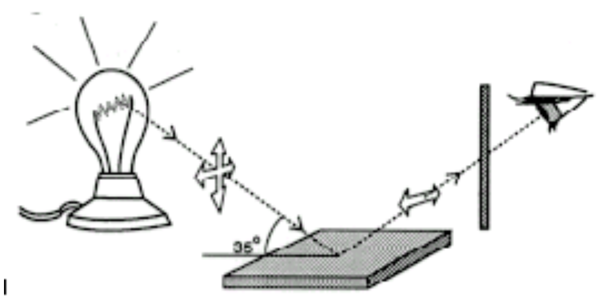


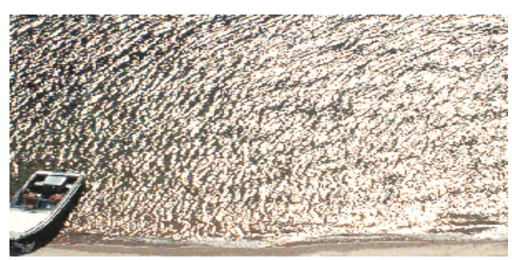
Different polarization of light get reflected and refracted with different amplitudes ("birefringence").

At one particular angle, the parallel polarization is NOT reflected at all! This is the "Brewster angle" θ_B, and $\theta_B + \theta_r = 90^o$.

$$n_1 \sin\theta_B = n_2 \sin(90^o - \theta_B) = n_2 \cos\theta_B$$

$$\tan\theta_B = \frac{n_2}{n_1}$$





Summary

- Law of **reflection** and **Snell's law:**

Reflection: $\theta_1' = \theta_1$

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

- Light of different wavelengths is refracted differently → **chromatic dispersion**
- **Total internal reflection**:

Critical Angle: $\theta_c = \sin^{-1}\dfrac{n_2}{n_1}$

- **Polarization** by reflection:

Brewster Angle: $\theta_B = \tan^{-1}\dfrac{n_2}{n_1}$