

Lecture 16

(Total Internal Reflection and Dispersion)

Physics 262-01 Spring 2019

Douglas Fields

https://phet.colorado.edu/sims/html/bending-light/latest/bending-light_en.html

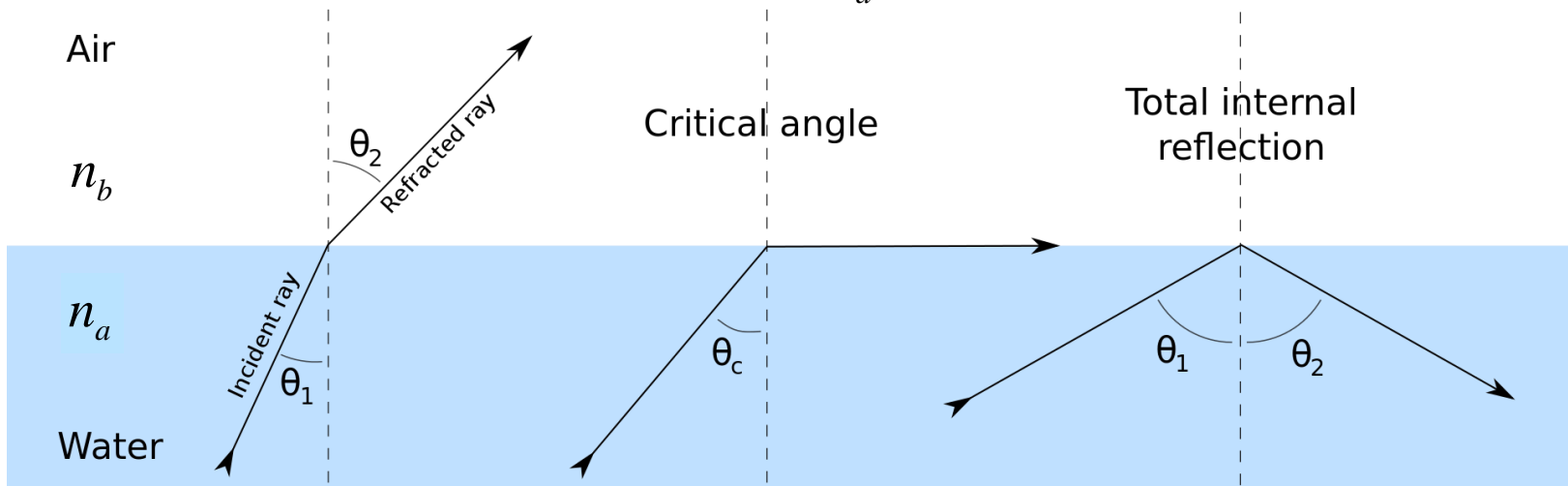
Reading Quiz

- In order to have total internal reflection, the index of refraction of the material with the incoming light must be
 - A) Less than the index of refraction of the other material.
 - B) Greater than the index of refraction of the other material.
 - C) The same as the index of refraction of the other material.
 - D) Larger than 2.0.
 - E) It doesn't matter.

Total Internal Reflection

- An interesting thing happens when light goes from a higher to a lower index of refraction...
- As the angle of incidence is increased, the refracted light is bent more and more parallel to the surface.
- At an angle (called the critical angle), the light is refracted completely parallel to the interface.
- At this point then, $n_a \sin \theta_a = n_b \sin \theta_b^1 \Rightarrow$

$$\sin \theta_{critical} = \frac{n_b}{n_a}$$

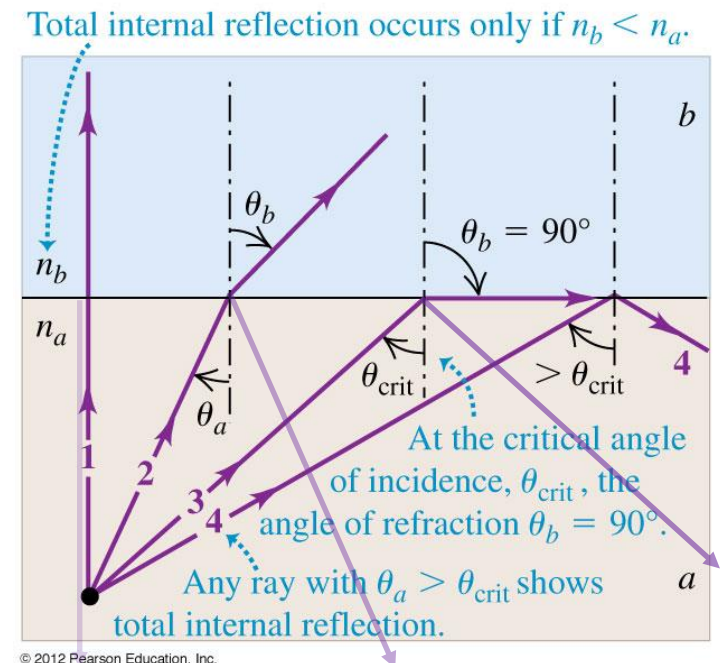


Total Internal Reflection

- Notice that this can only happen when $n_a > n_b$
- What the previous picture didn't show is that there is also reflection at the other angles!
- The fraction that is reflected increases up to the critical angle, and then is 100%.

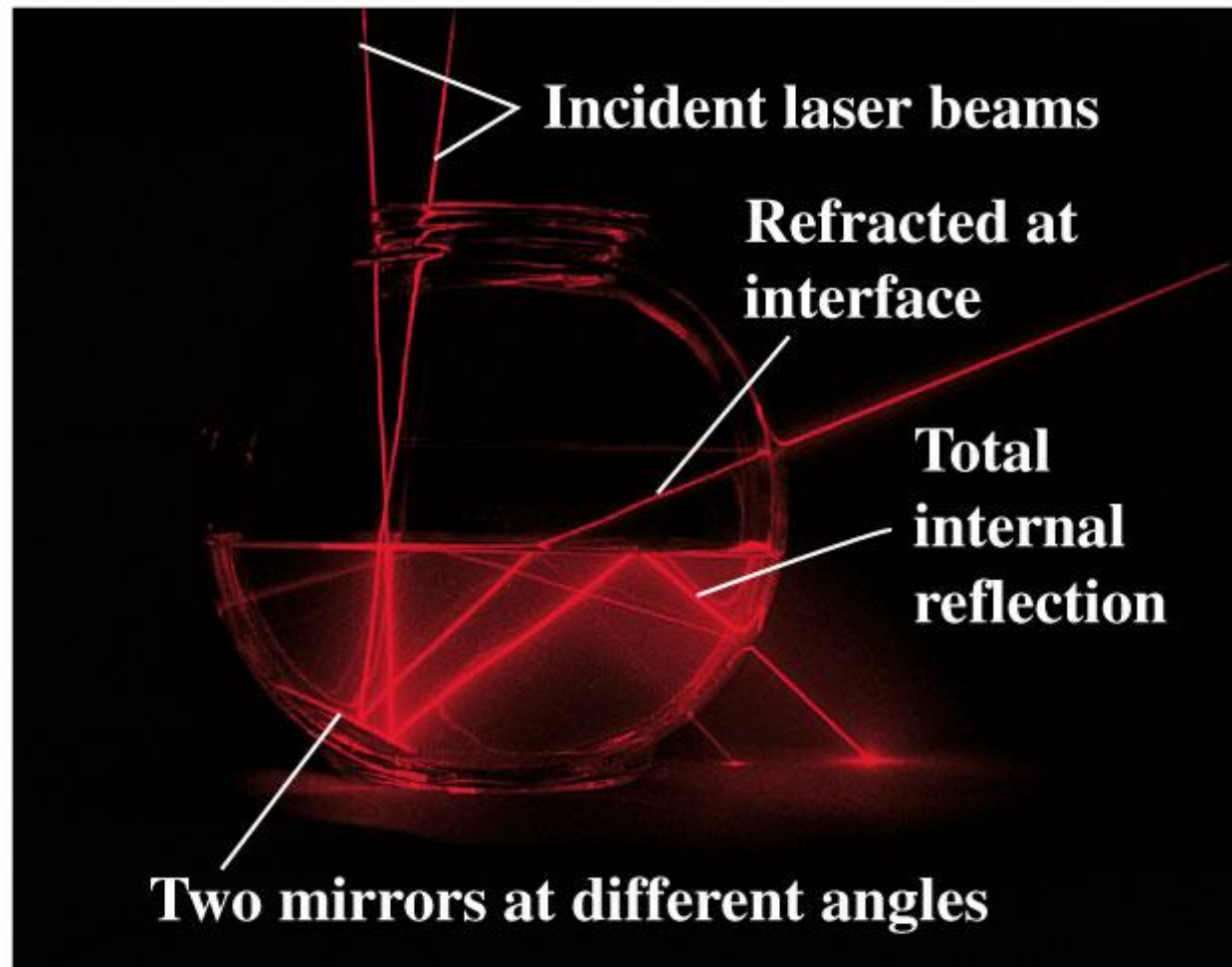
$$\sin \theta_{critical} = \frac{n_b}{n_a}$$

(a) Total internal reflection



See?

(b) Total internal reflection demonstrated with a laser, mirrors, and water in a fishbowl




Light passes **from** a medium of index of refraction n_a **into** a second medium of index of refraction n_b . The critical angle for total internal reflection is θ_{crit} .

In order for total internal reflection to occur, what must be true about n_a , n_b , and the incident angle θ_a ?

- A. $n_a > n_b$ and $\theta_a > \theta_{\text{crit}}$
- B. $n_a > n_b$ and $\theta_a < \theta_{\text{crit}}$
- C. $n_a < n_b$ and $\theta_a > \theta_{\text{crit}}$
- D. $n_a < n_b$ and $\theta_a < \theta_{\text{crit}}$

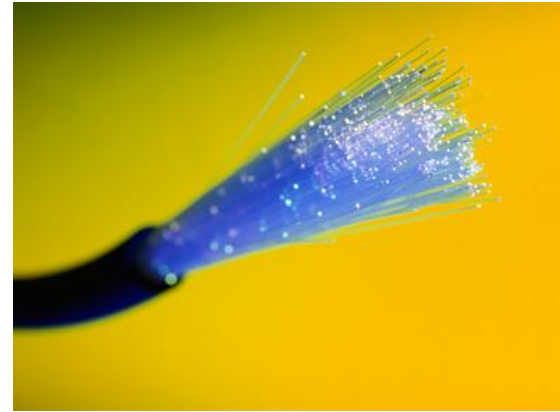
Light passes from a medium of index of refraction n_a into a second medium of index of refraction n_b . The critical angle for total internal reflection is θ_{crit} .

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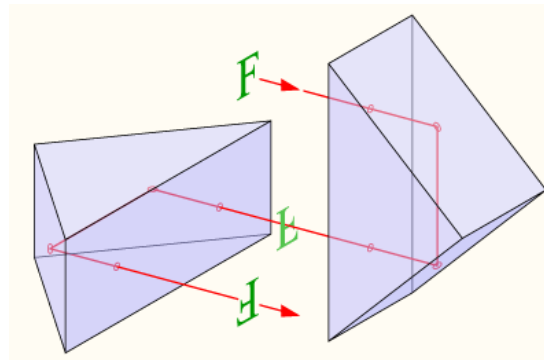
-  A. $n_a > n_b$ and $\theta_a > \theta_{\text{crit}}$
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- C. $n_a < n_b$ and $\theta_a > \theta_{\text{crit}}$
- D. $n_a < n_b$ and $\theta_a < \theta_{\text{crit}}$

Uses

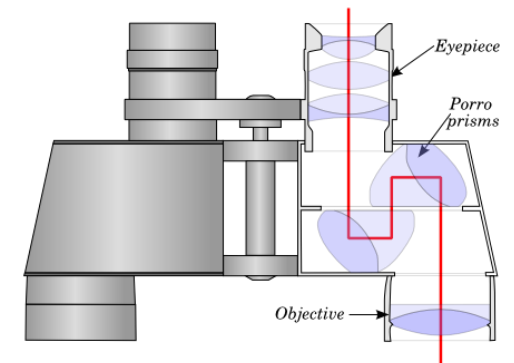
- Fiber Optics



- Porro Prisms



- Endoscopes

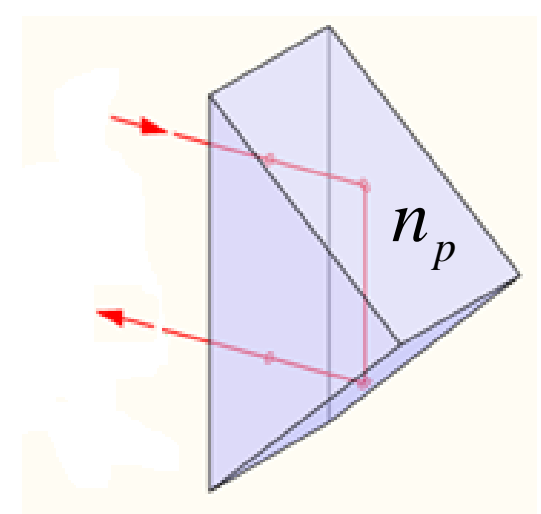


- Diamonds...



Exercise

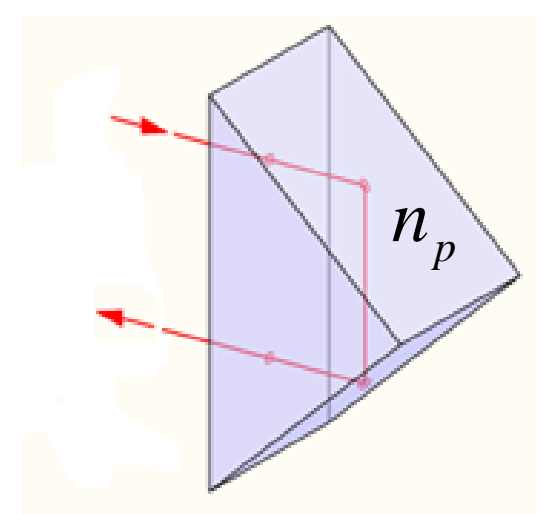
- A porro prism made of a material with index of refraction n_p **just barely** gives *total* internal reflection when immersed in water. What is the index of refraction n_p ?



$$n_{H_2O} = 1.333$$

Exercise

- A porro prism made of a material with index of refraction n_p just barely gives *total* internal reflection when immersed in water. What is the index of refraction n_p ?



$$n_{H_2O} = 1.333$$

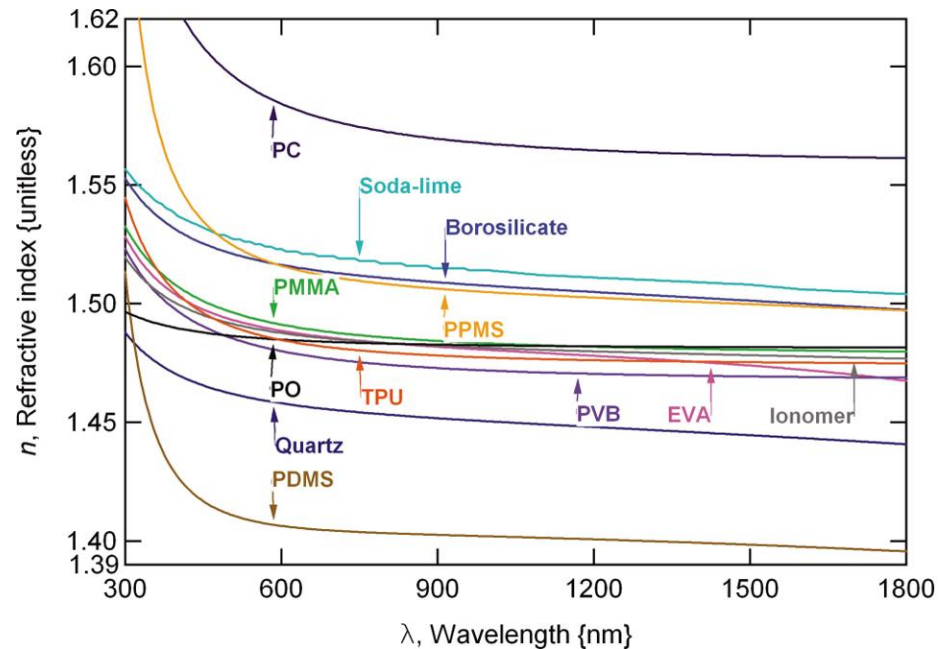
$$\sin \theta_c = \frac{n_b}{n_a}$$

$$\sin 45^\circ = \frac{1.333}{n_a} \Rightarrow$$

$$n_a = \frac{1.333}{\sin 45^\circ} = \frac{1.333}{0.707} = 1.886$$

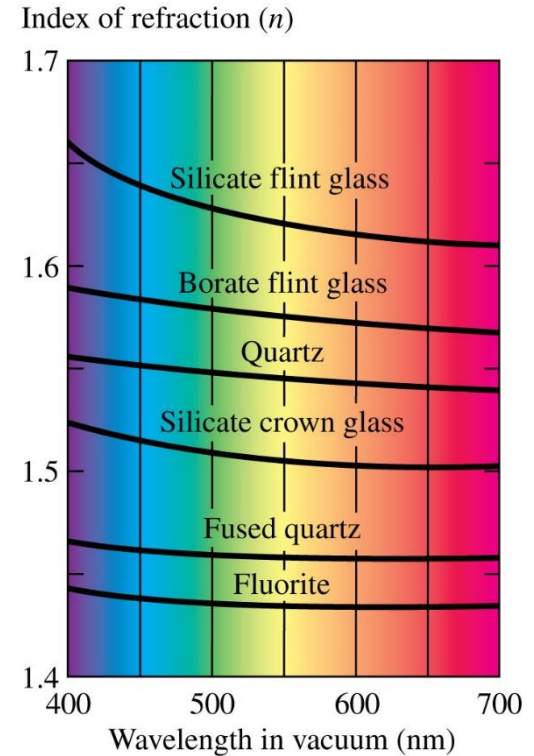
Dispersion

- Until now, we have considered that the index of refraction of a material is independent of the wavelength of the light.
- The different speeds of light in materials is caused by moving charges in the material absorbing and reemitting light at the same frequency but with a slight change in phase.
- The change in phase can also be wavelength dependent, causing dispersion.

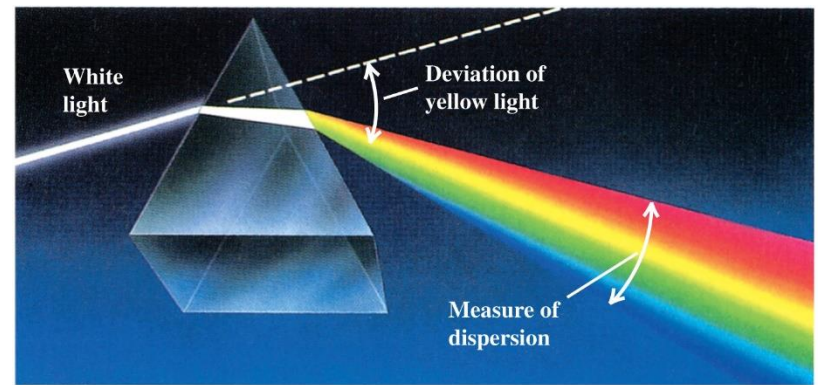


Prisms

- Non-monochromatic light (e.g., white light) can be separated into its components through the use of a prism, which relies on dispersion.
- Shorter wavelengths see a higher index of refraction and are therefore refracted more than longer wavelengths.
- One can use this to analyze the color spectrum of a source, but there are better methods to do that which we will discuss later.



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Got to love NM!

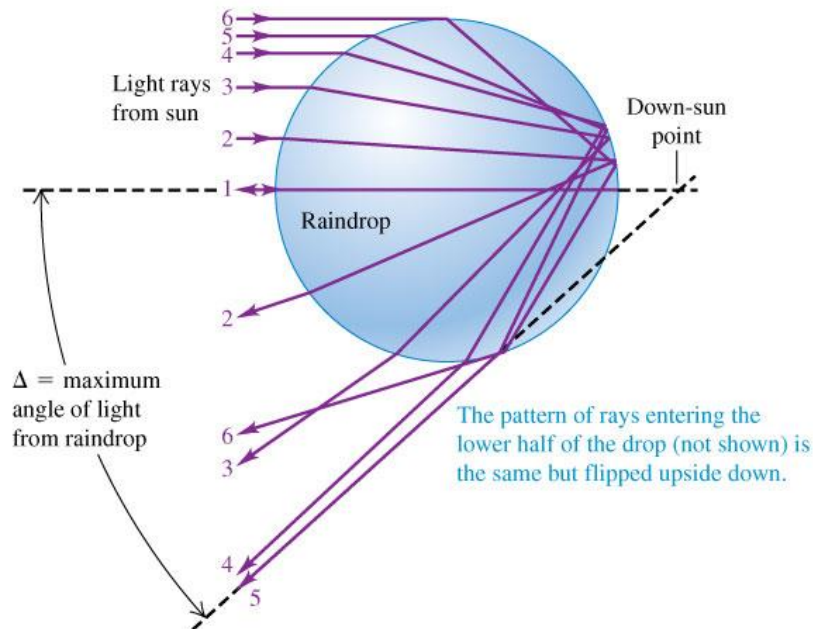




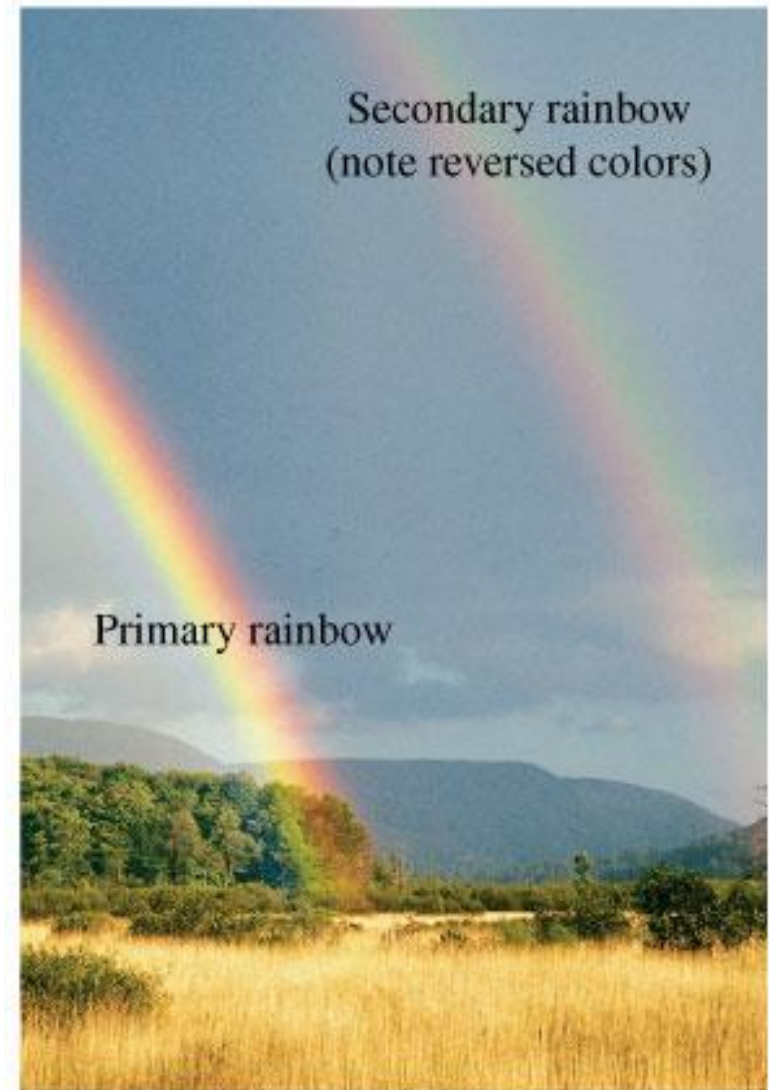
Rainbows

- Rainbows are another excellent example of dispersion.
- Without dispersion:

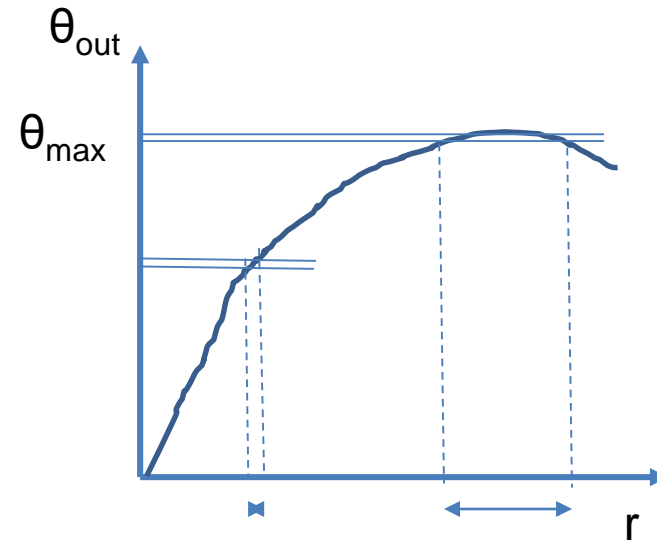
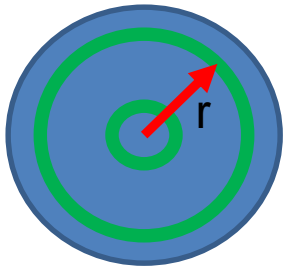
(b) The paths of light rays entering the upper half of a raindrop



(a) A double rainbow



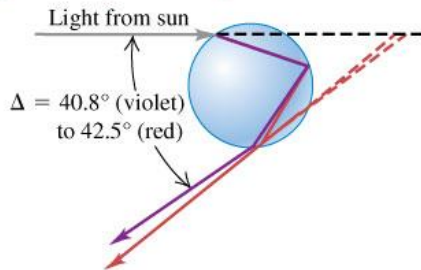
Colors



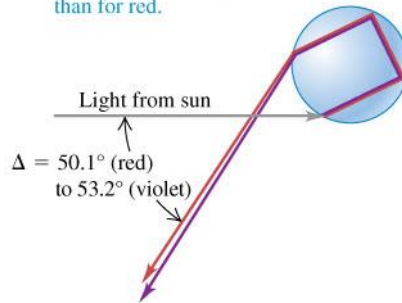
Rainbows

- Rainbows are another excellent example of dispersion.

(d) A primary rainbow is formed by rays that undergo two refractions and one internal reflection. The angle Δ is larger for red light than for violet.

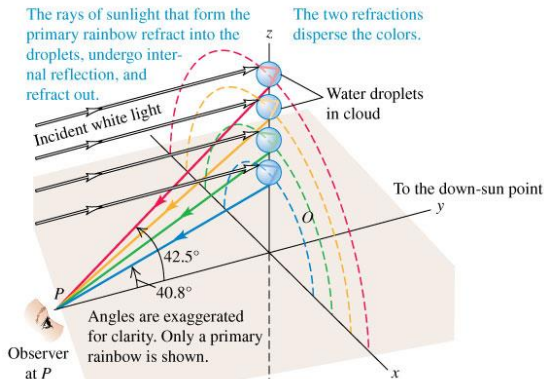


(e) A secondary rainbow is formed by rays that undergo two refractions and two internal reflections. The angle Δ is larger for violet light than for red.



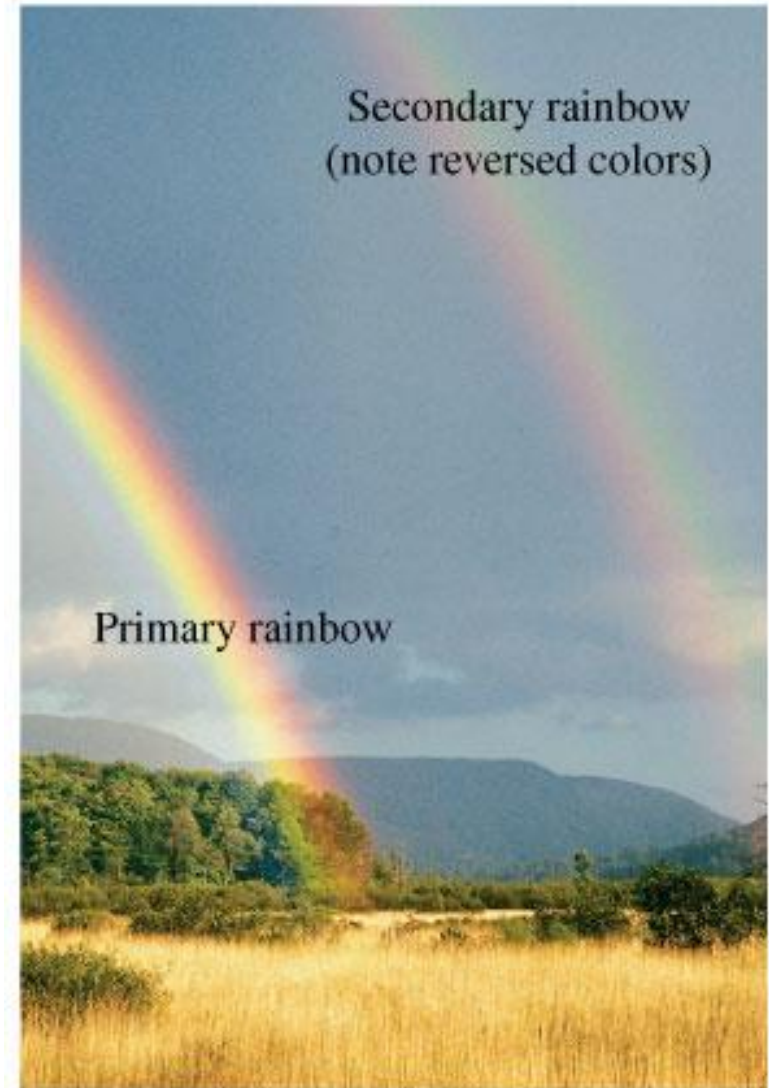
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(c) Forming a rainbow. The sun in this illustration is directly behind the observer at P.



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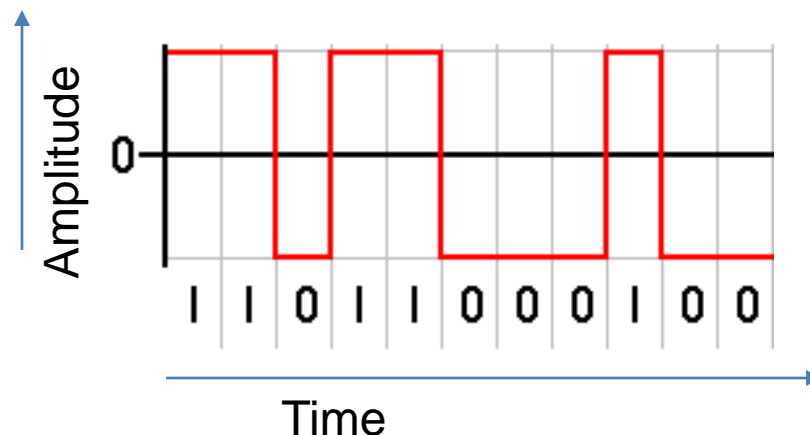
(a) A double rainbow



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Dispersion in Fiber Optics

- Okay, now let's think about dispersion in fiber optics.
- How do you send a signal down a fiber optic cable?
- A: a laser. But that is monochromatic, so no dispersion, right?
- But you have to send information, so the light beam must be modulated (amplitude must change with time) to carry that information.



Dispersion in Fiber Optics

- Once you modulate the amplitude, you no longer have a sinusoidal wave.
- That wave (let's take a simple square-wave function) is now a combination of frequencies, which can be determined by a Fourier transform of the square-wave.
- Each of these frequencies travel down the fiber optic at different velocities, determined by the dispersive properties of the glass.
- This limits the distance that signals can travel without re-modulation.

$$\phi(t) = \sum_{n=1}^{\infty} c_n \varphi_n(t)$$

$$\phi_{\text{square}}(t) = \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{\sin(2\pi(2n-1)ft)}{2n-1}$$

