Physics 1C

Lecture 25B

"*If you want the rainbow, you gotta put up with the rain.*"

--Dolly Parton

Outline

Refraction review

Mirages (TIR).

Huygen’s Principle.

Prisms.

Dispersion.

Rainbows.

Mirages

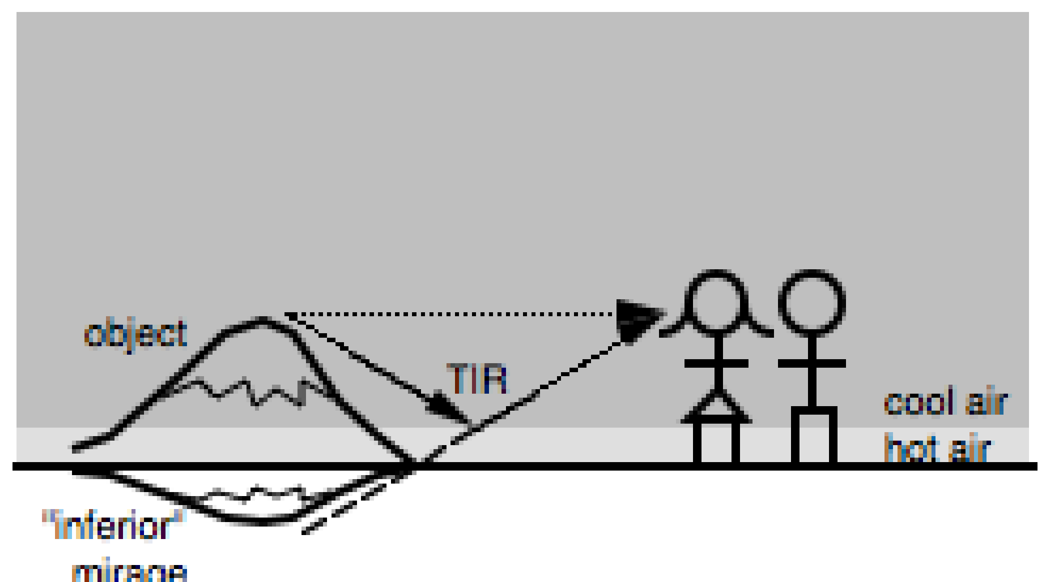
Mirages occur because of total internal reflection (TIR).

Hot air is less dense than cool air.

The less dense hot air has a small index of refraction n

The more dense cool air has a higher n.

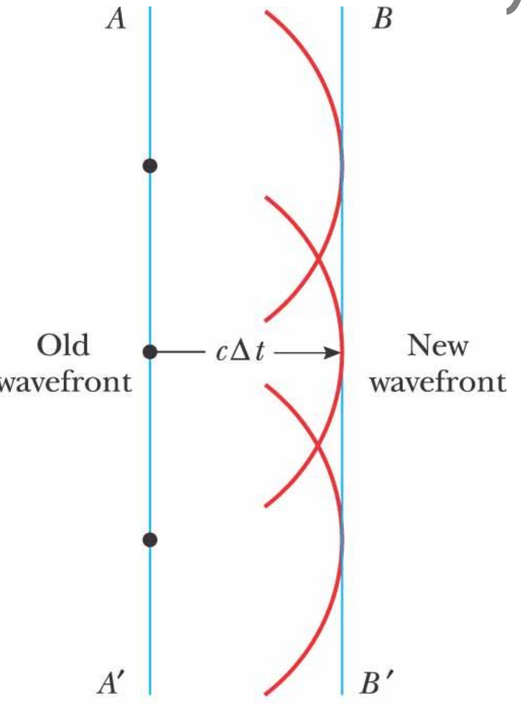
TIR - light in cool air (slow) off of hot air (fast).



Huygens's Principle

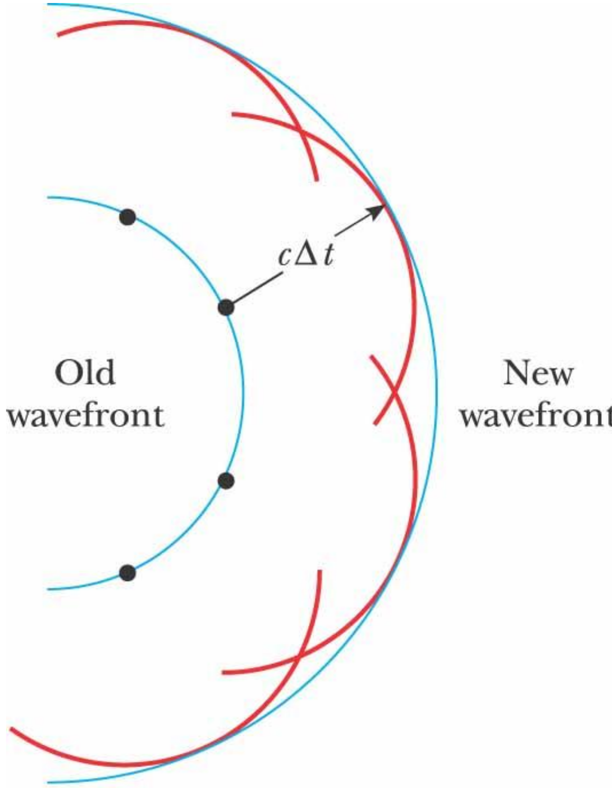
Christiaan Huygens (1629-1695) introduced a geometric construction that helped to understand many practical aspects of propagation of light.

In this construction, all points of a wave front are taken as point sources for the production of secondary waves, called **wavelets**.



(a)

New position of the wave front after time Δt has elapsed is the surface tangent to the wavelets.



(b)

Huygens's Principle

We can use Huygens's principle to derive the laws of reflection and refraction.

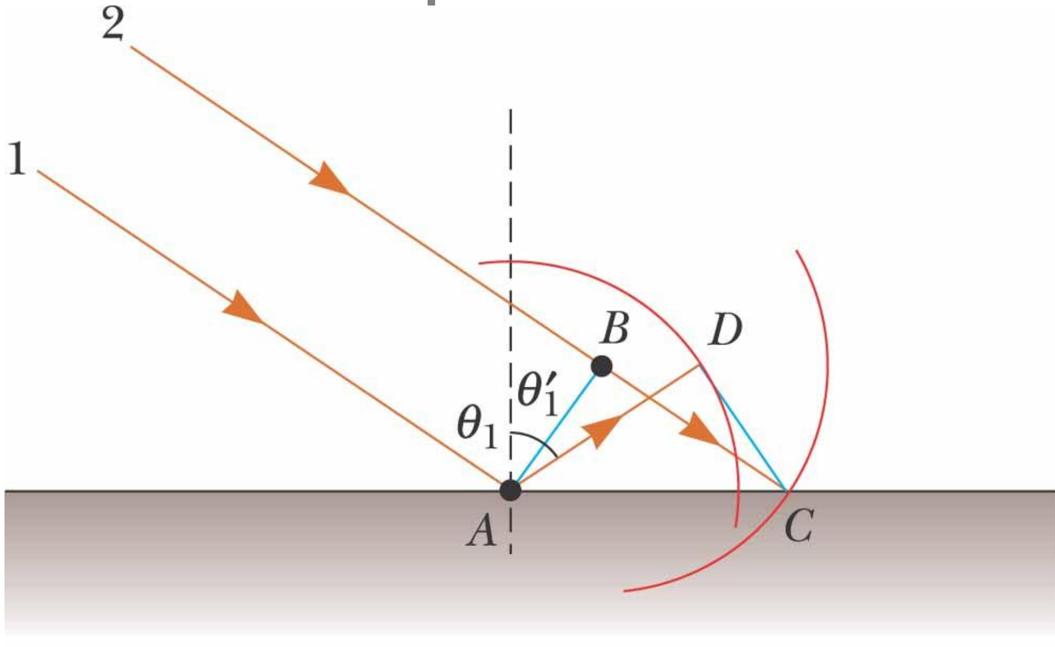
AB is a wave front of incident light.

Point A sends out a wavelet toward point D.

Point B sends out a wavelet toward point C.

Both rays move with the same speed:
AD = BC = $c\Delta t$

Let's isolate congruent triangles ABC and ADC



(a)

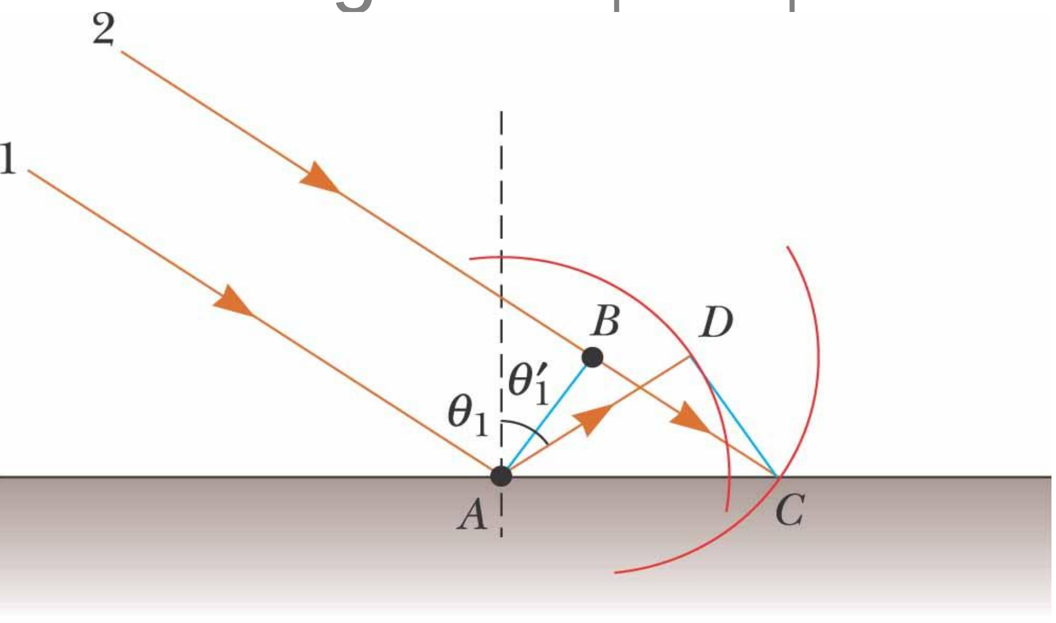
Huygens's Principle

ABC and ADC are congruent because they share hypotenuse AC and because AD = BC.

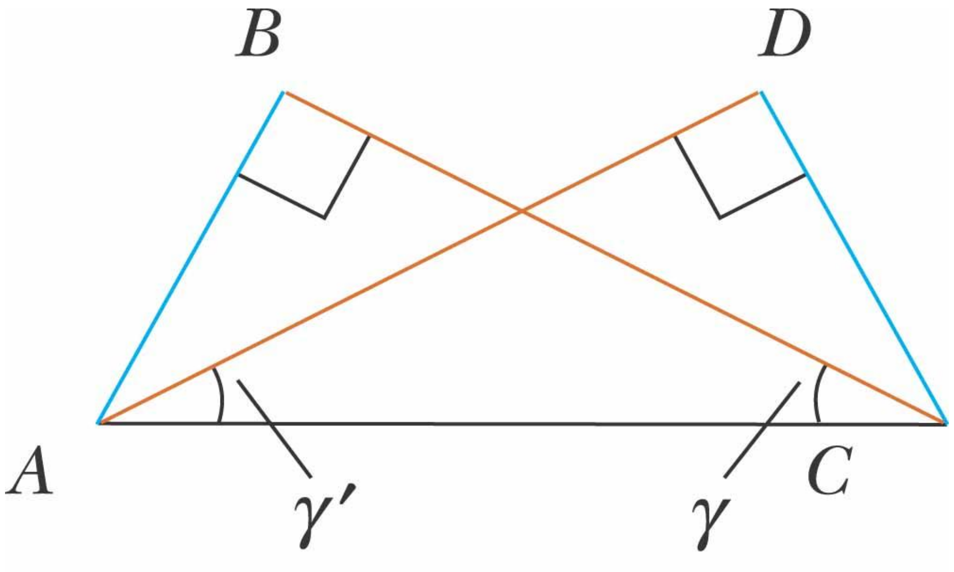
We have: cos γ = BC / AC cos γ' = AD / AC.

Therefore, cos γ = cos γ' and $\gamma = \gamma'$

This gives $\theta_1 = \theta_1'$ which is the **law of reflection**



(a)

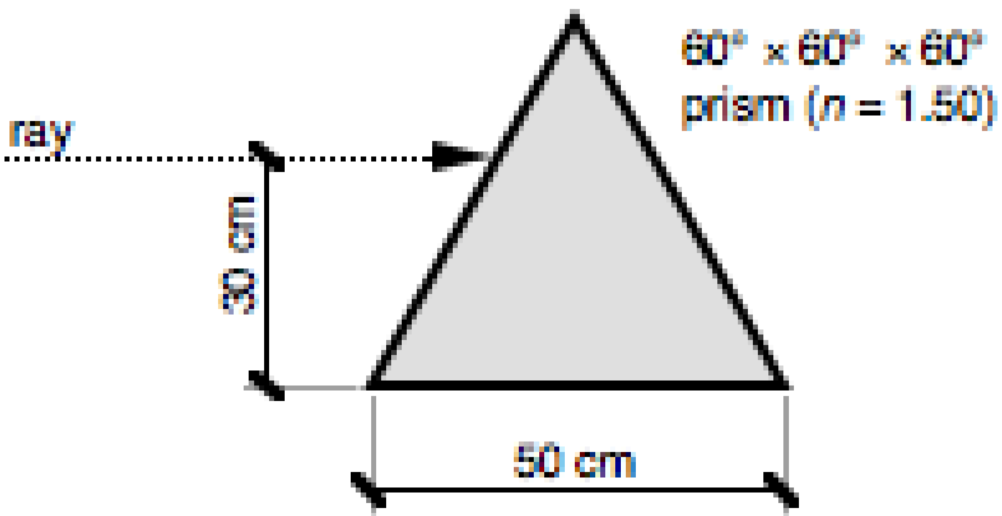


(b)

Prisms

Example

An incident ray in air is headed straight towards an equilateral plastic prism (n = 1.50). The ray is parallel to the bottom of the prism. Use Snell's Law to find the angle (with respect to the normal) that the light ray exits the prism on the right.



Answer

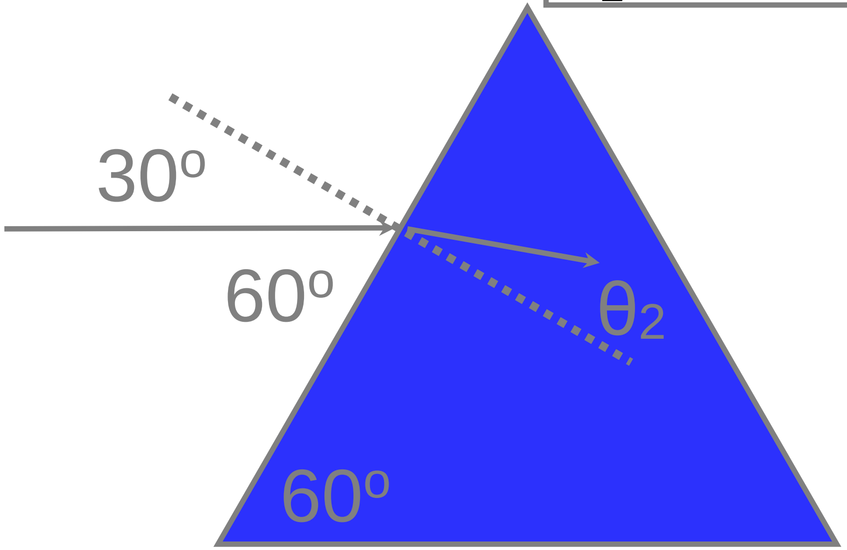
The diagram is given but it is up to you to draw the normal(s) and path of the ray.

Prisms

Answer

Start with:

$$\theta_2 = 19.47°$$



Thus, the incident angle is 30º from air to plastic. Using Snell's Law we find:

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

$$\theta_2 = \sin^{-1}\left(\frac{n_1}{n_2}\sin\theta_1\right)$$

$$\theta_2 = \sin^{-1}\left(\frac{1}{1.5}\sin 30°\right) = \sin^{-1}(0.333)$$

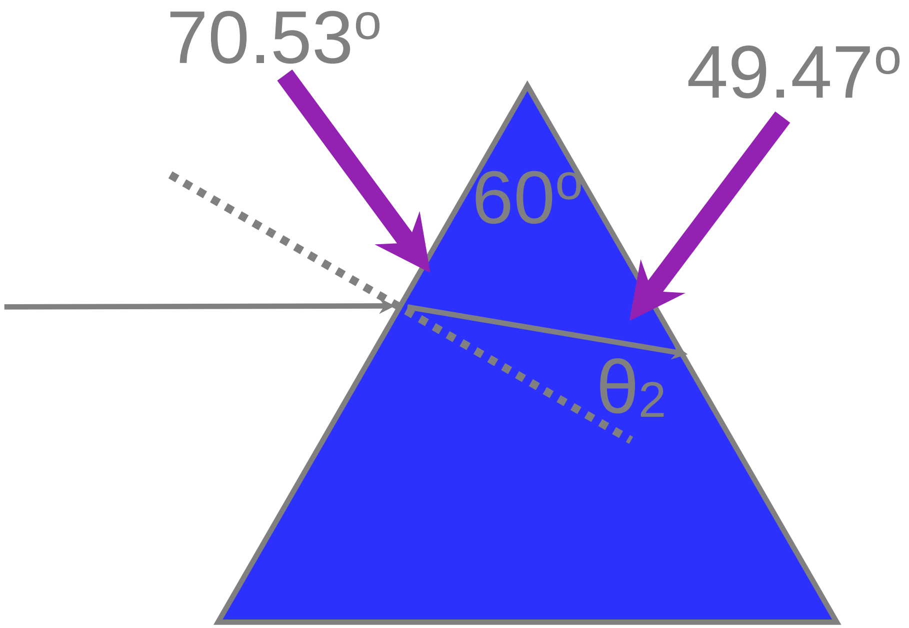
Prisms

Answer

Now, we need to look at the second boundary.

We can now examine the small top triangle created by the ray in the prism.

The bottom left angle on this triangle will be:



$$90° - 19.47° = 70.53°$$

This means that the bottom right angle of the triangle will be:

$$180° - 70.53° - 60° = 49.47°$$

Prisms

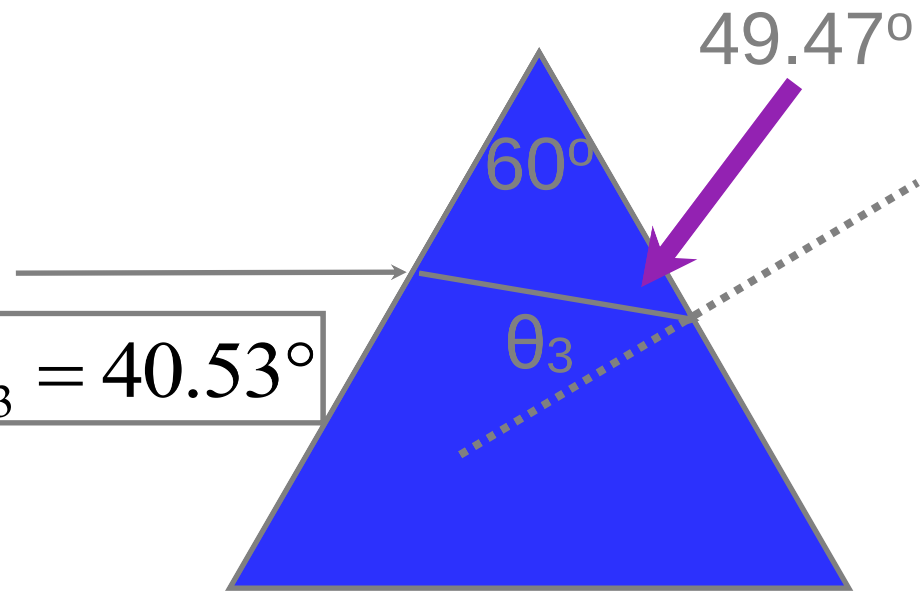
Answer

Is the 49.47°, the angle we will use in Snell's Law?

No, it is not with respect to the normal.

We draw the normal and find:

$$90° - 49.47° = 40.53°$$



$$\theta_3 = 40.53°$$

At the second boundary, will this ray be refracted or totally internally reflected?

Check by calculating the critical angle.

refracted, barely

$$\sin\theta_c = \frac{n_1}{n_2}$$

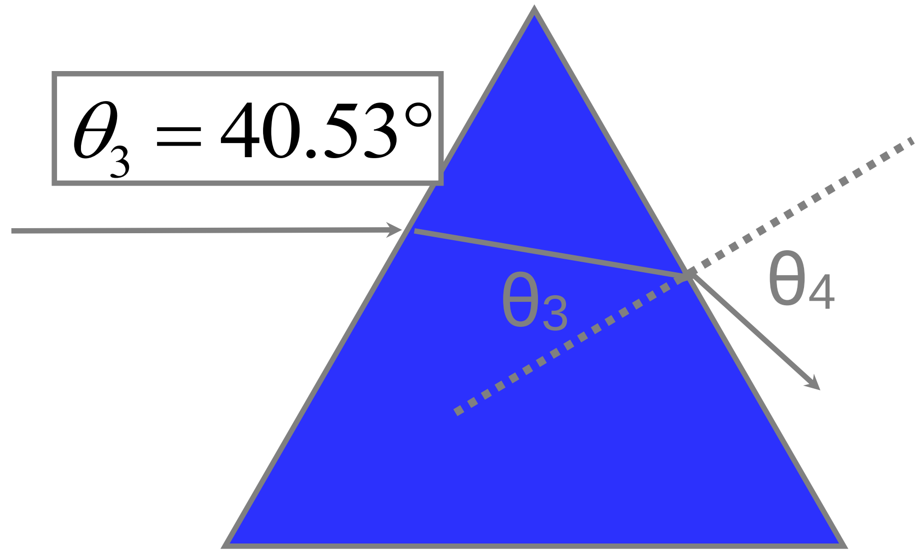
$$\theta_c = \sin^{-1}\left(\frac{1}{1.5}\right) = \sin^{-1}(0.667)$$

$$\theta_c = 41.81°$$

Prisms

Answer

Now we need to calculate the outgoing ray with Snell's Law again:



$$n_2 \sin\theta_3 = n_1 \sin\theta_4$$

$$\theta_4 = \sin^{-1}\left(\frac{n_2}{n_1}\sin\theta_3\right)$$

$$\theta_4 = \sin^{-1}\left(\frac{1.5}{1}\sin 40.53°\right) = \sin^{-1}(0.975)$$

$$\theta_4 = 77.10°$$

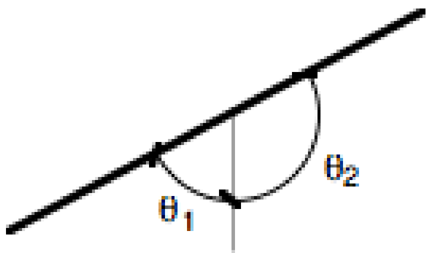
This is the outgoing angle with respect to the normal

Prisms

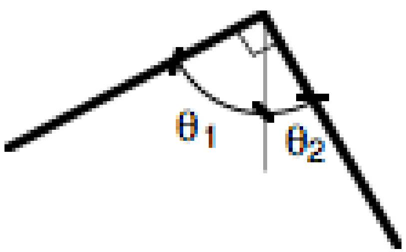
Answer

Overall, this incident ray will be pushed downward compared to its original direction.

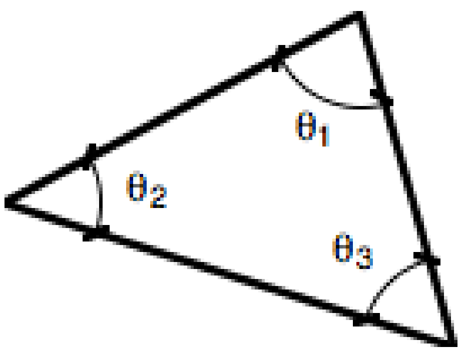
Don't forget your geometry when dealing with prisms and Snell's Law.



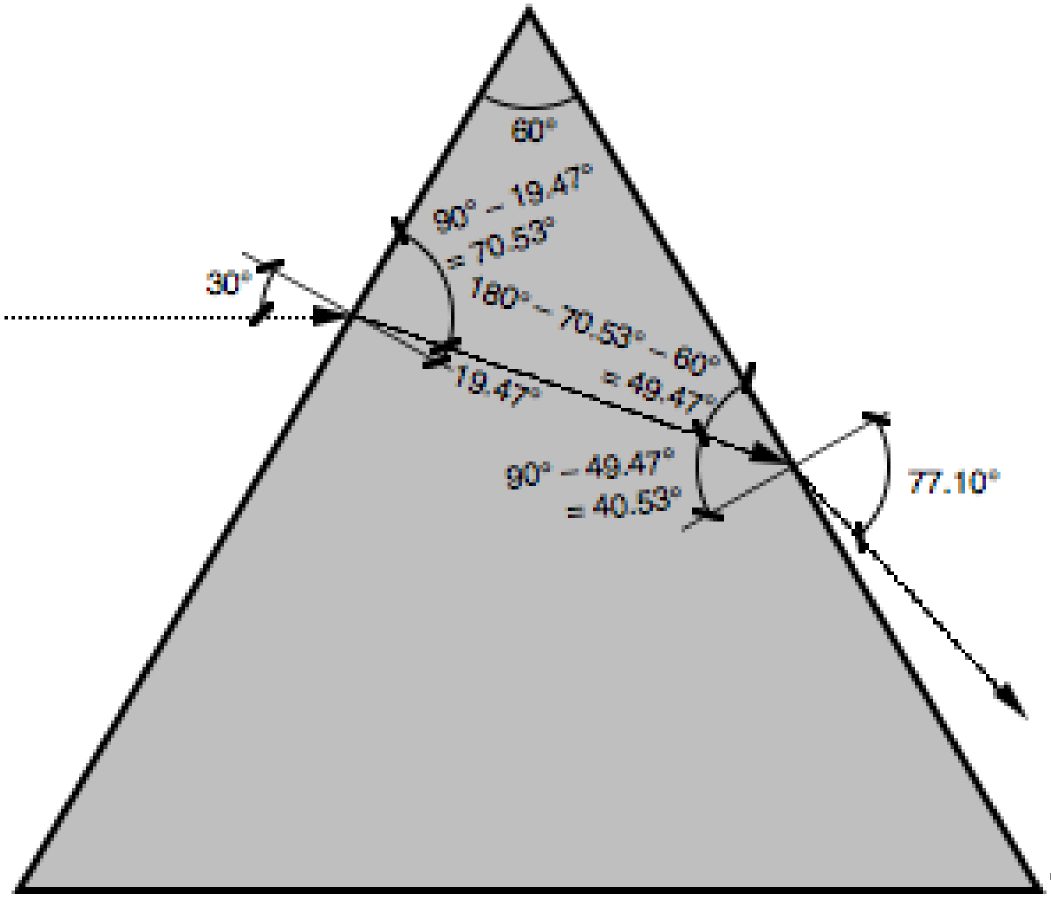
$\theta_1+\theta_2 = 180^o$



$\theta_1+\theta_2 = 90^o$



$\theta_1+\theta_2+\theta_3=180^o$



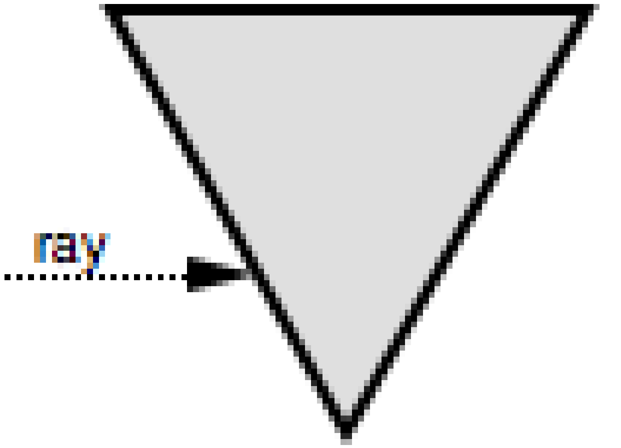
Clicker Question 25B-1

In the prism example we just performed, a light ray was deflected downward when it moved through a prism when the pointy side was up. If you inverted the prism (so the pointy side was down) how would the direction of the incident ray change after passing completely through the front and back sides of the prism?

A) The light ray would still be deflected downward.

B) The light ray would now be deflected upward.

C) The light ray would not be deflected (it would move in the same direction that it had originally).



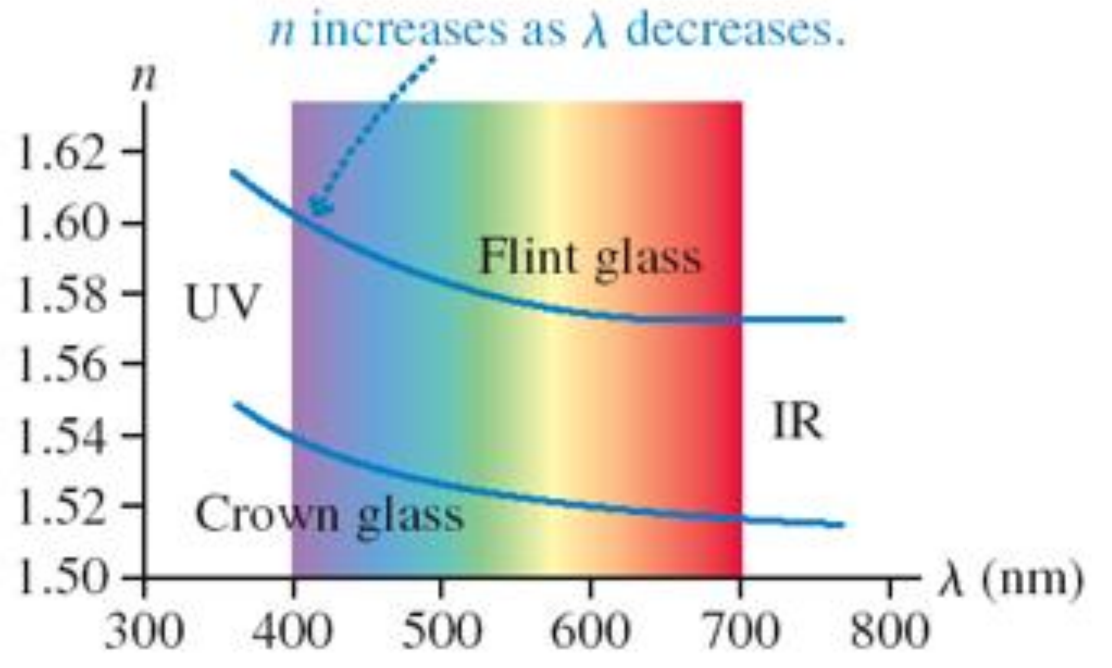
Dispersion

The index of refraction in anything except a vacuum depends on the wavelength of the light.

The dependence of *n* on *λ* is called **dispersion**.

Snell's Law indicates that the angle of refraction made when light enters a material depends on the wavelength of the light.

The index of refraction for a material usually decreases with increasing wavelength.



Dispersion

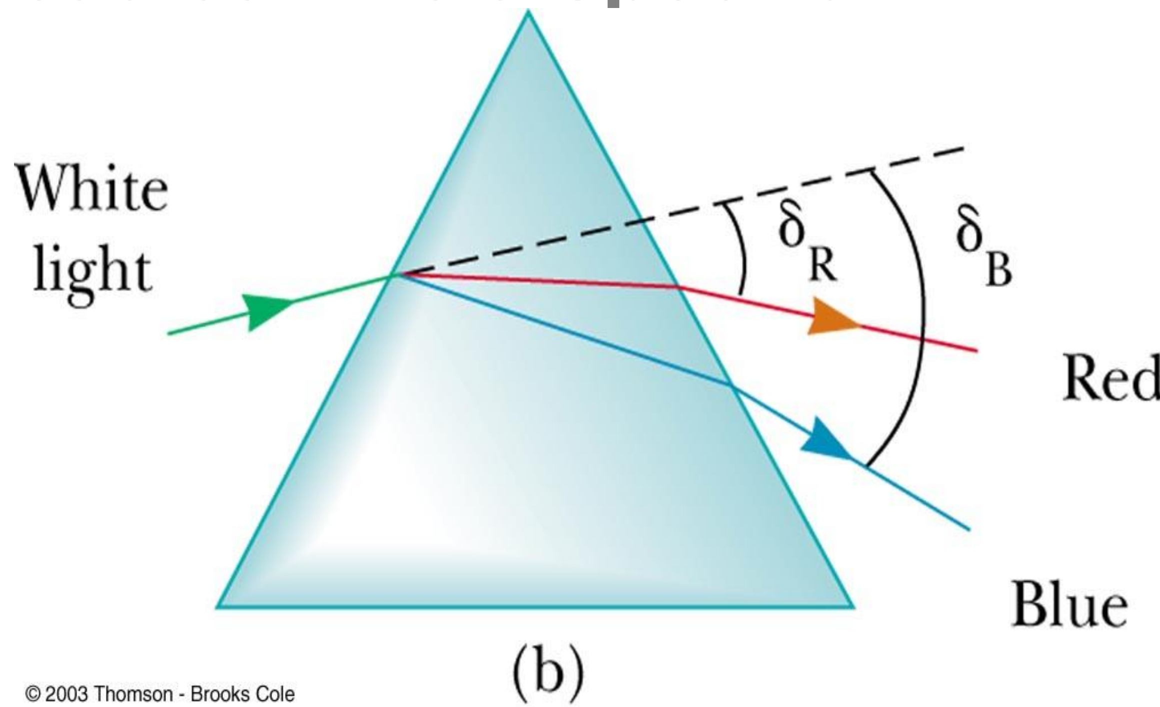
This means that **violet light refracts more than red** light when passing from air into a material.

The amount the ray is bent away from its original direction is called the **angle of deviation**, δ.

Since all the colors have different angles of deviation, they will spread out into a **spectrum**.

Violet deviates the most.

Red deviates the least.



Clicker Question 25B-2

If n_{water} =1.33 and n_{glass} =1.50, then total internal reflection at an interface between this glass and water:

A) occurs whenever the light goes from glass to water.

B) occurs whenever the light goes from water to glass.

C) may occur when the light goes from glass to water.

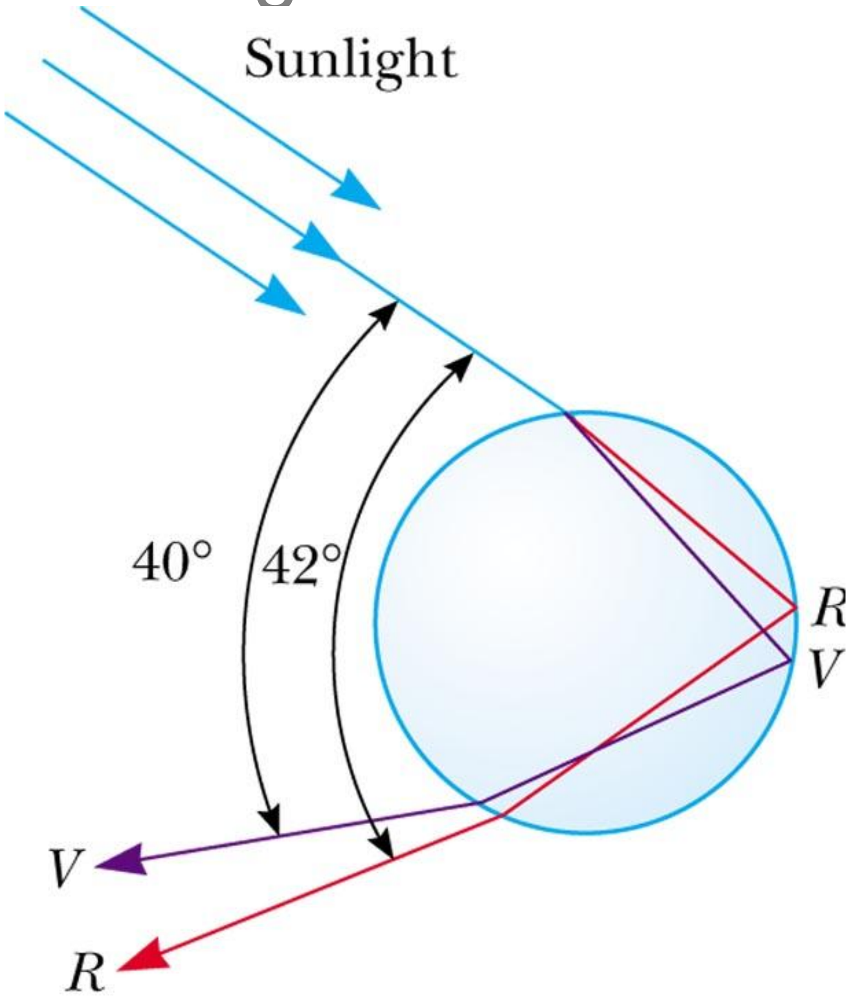
D) may occur when the light goes from water to glass.

E) can never occur at this interface.

Rainbows

Rainbows appear when a ray of light strikes a drop of water in the atmosphere.

The incident white light ray will undergo both reflection and refraction.



At the first boundary (air-water), refraction will occur (with red deviating the least).

At the second boundary (water-air), reflection will occur.

It refracts again as it hits a third boundary (water-air).

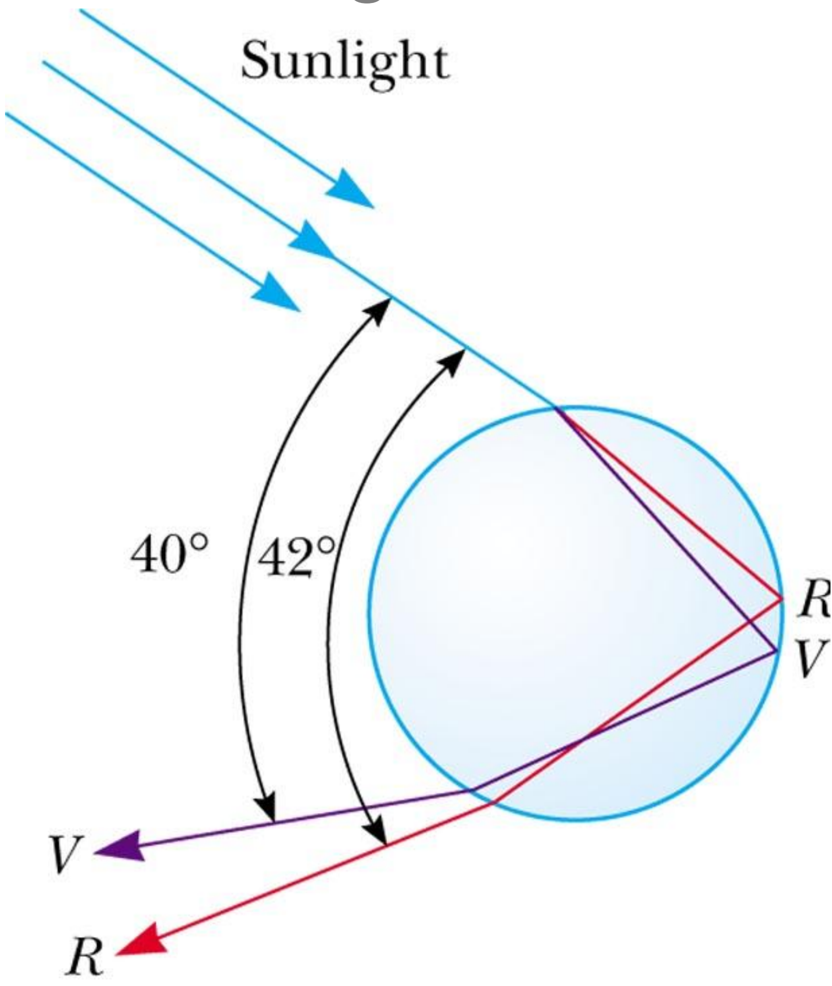
Rainbows

The angle between the incident white light and the violet ray is 40º.

The angle between the incident white light and the red ray is 42º.

All of the other visible colors will lie in between violet and red.

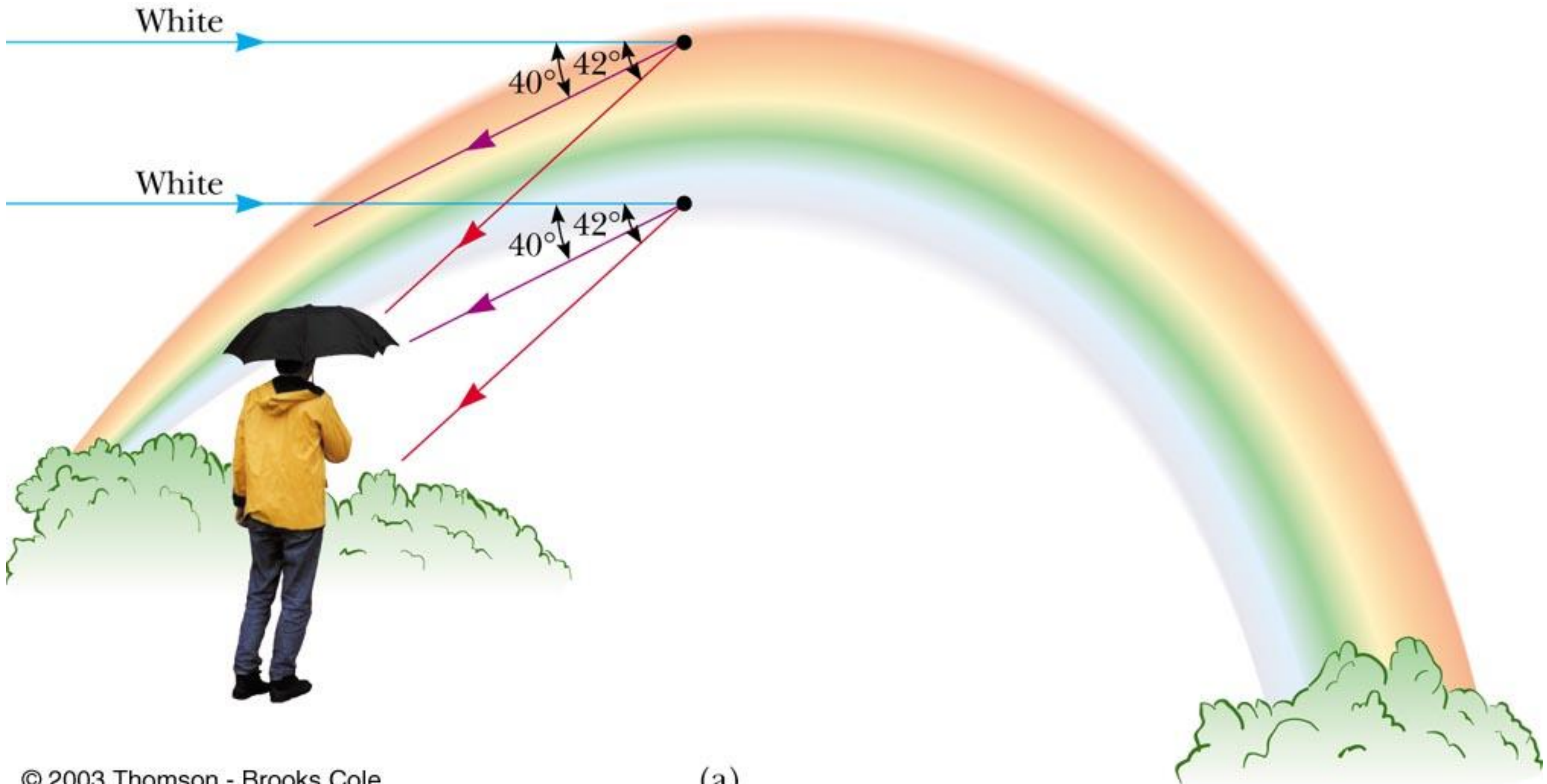
When you see a rainbow in the sky you are actually seeing this happen in many, many raindrops.



Rainbows

For a raindrop very high in the sky, red will be bent more and will be directed toward the observer.

A raindrop lower in the sky would direct violet toward the observer.



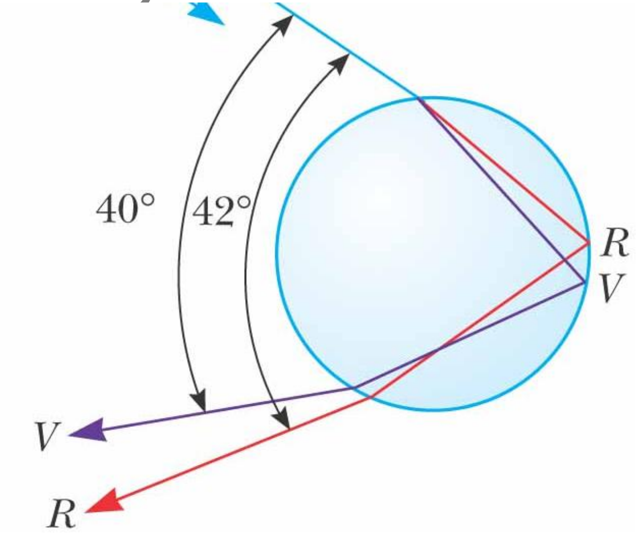
(a)

Double Rainbow

The secondary rainbow is fainter than the primary and its colors are reversed.

The secondary rainbow arises from light that makes two reflections from the interior surface before exiting the raindrop.

Higher order rainbows are possible, but their intensity is low.



For Next Time (FNT)

Start reading Chapter 26

Start working on the homework for Chapter 25