The law of reflection:

$$\theta_1 = \theta_1'$$

The law of refraction:

$$n_2 \sin\theta_2 = n_1 \sin\theta_1$$ **Snell's Law**

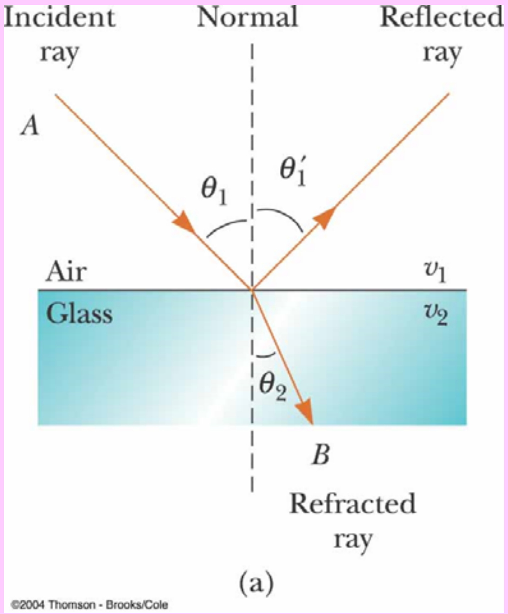
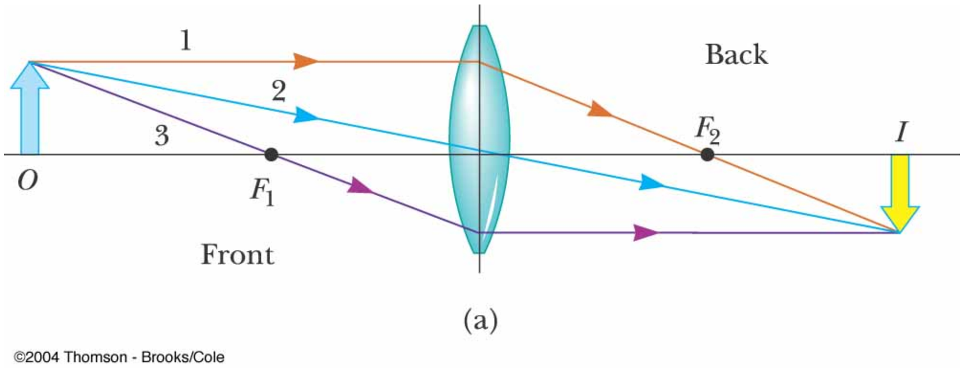
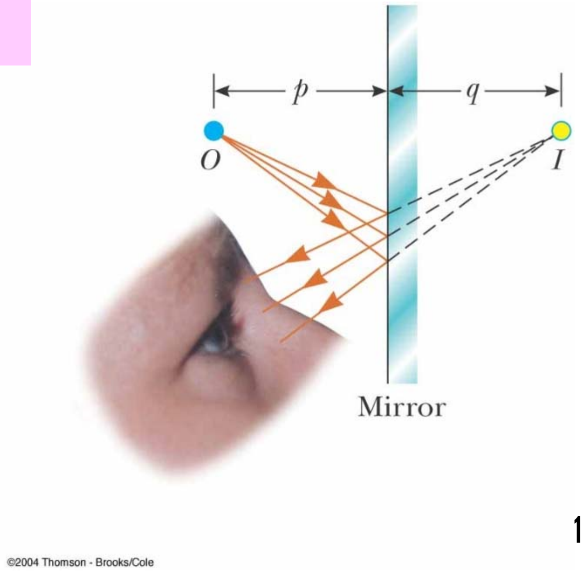


Image formation





Reading: Chapter 23

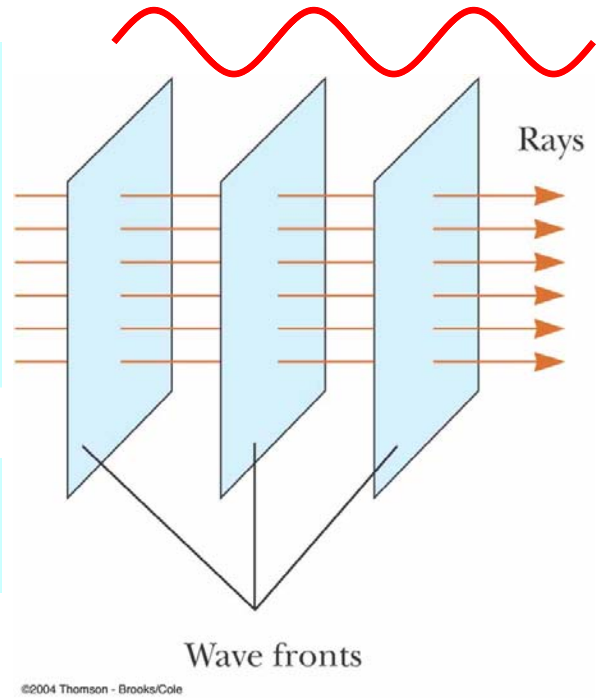
Chapter 23

Propagation of Light - Ray Optics

Propagation of Light – Ray (Geometric) Optics

Main assumption:

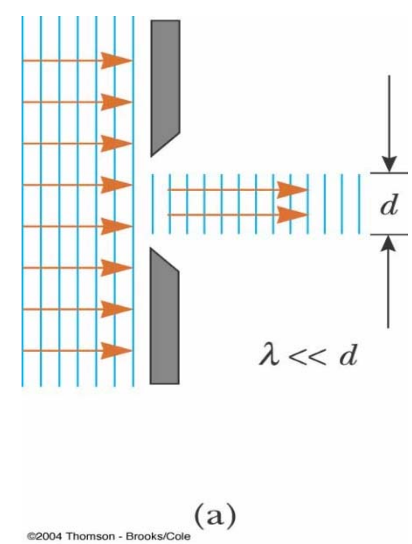
- **light travels in a straight-line path in a uniform medium and**
- **changes its direction when it meets the surface of a different medium or**
- **if the optical properties of the medium are nonuniform**



The rays (directions of propagation) are straight lines perpendicular to the wave fronts

The above assumption is valid only when the size of the barrier (or the size of the media) is much larger than the wavelength of light

$$\lambda << d$$



Main Question of Ray Optics:

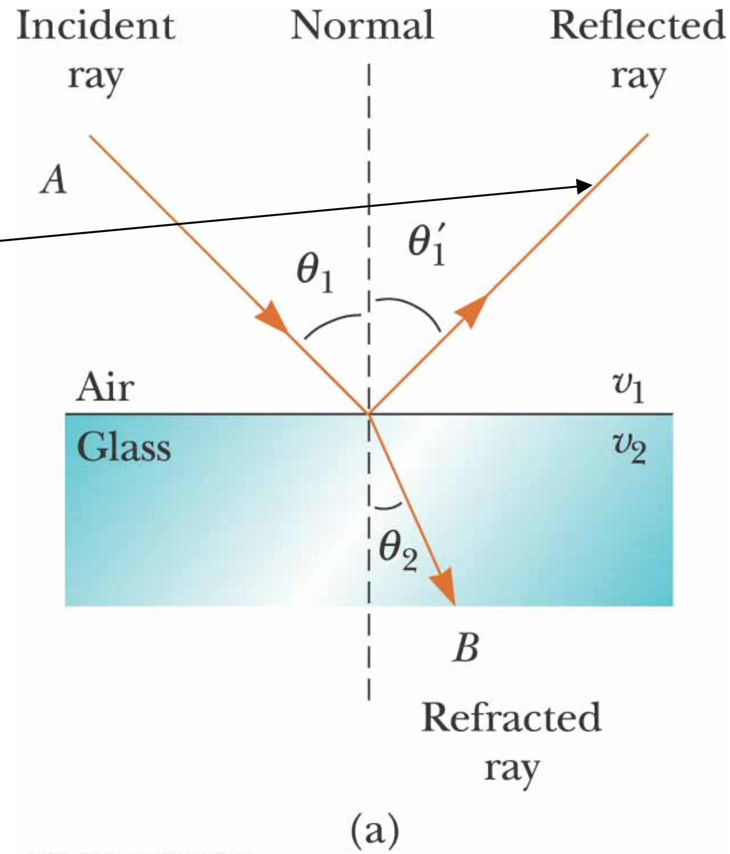
What happens to light at the boundary between two media?

Propagation of Light - Ray Optics

What happens to light at the boundary between two media?

The light can be

- **reflected or**
- **refracted (transmitted)**



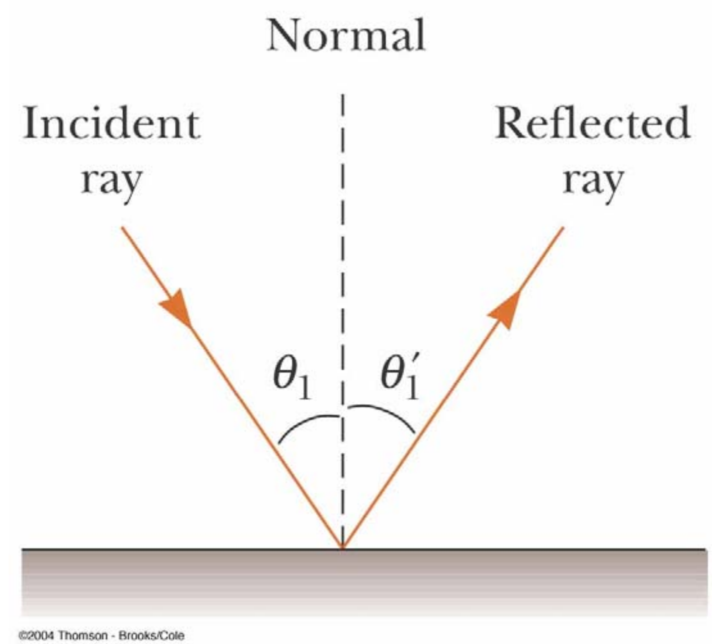
Reflection of Light

The law of reflection:

The angle of reflection is equal to the angle of incidence

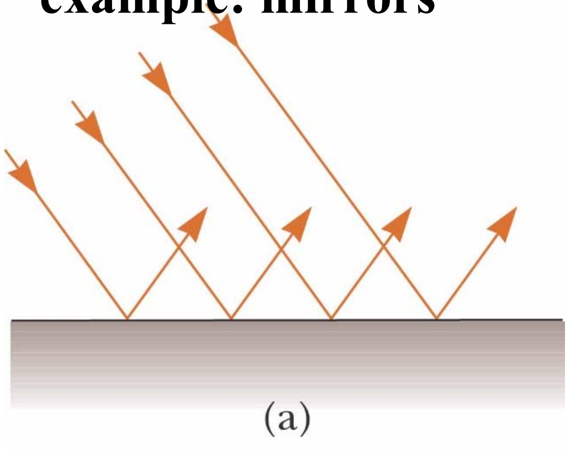
$$\theta_1 = \theta_1'$$

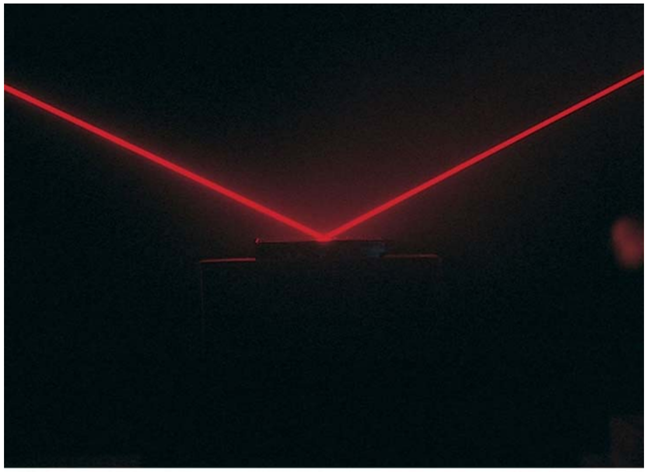
The incident ray, the reflected ray and the normal are all in the same plane



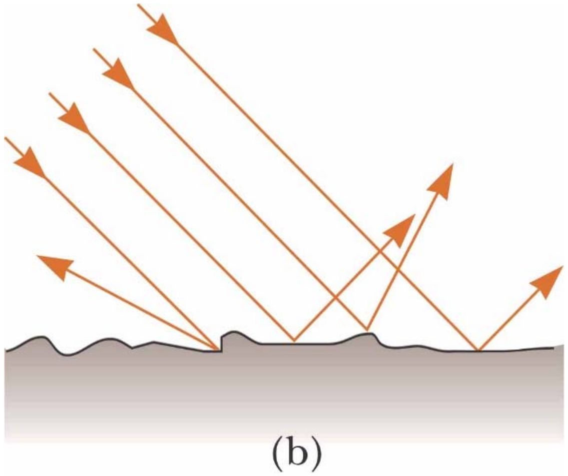
Reflection of Light

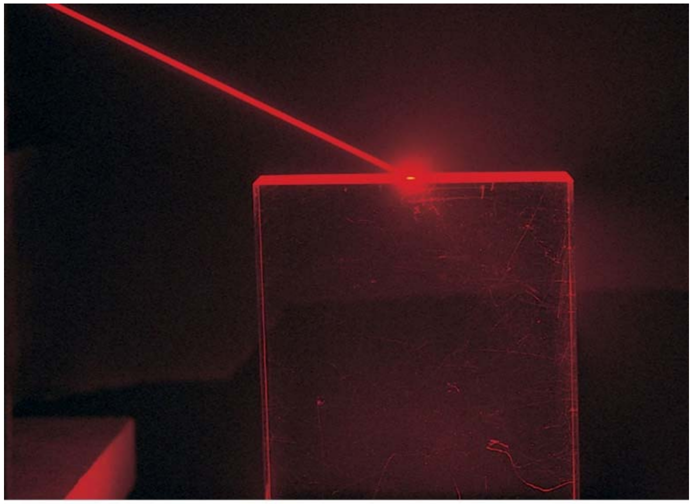
Specular reflection
(reflection from a smooth surface) – example: mirrors





Diffuse reflection
(reflection from a rough surface)



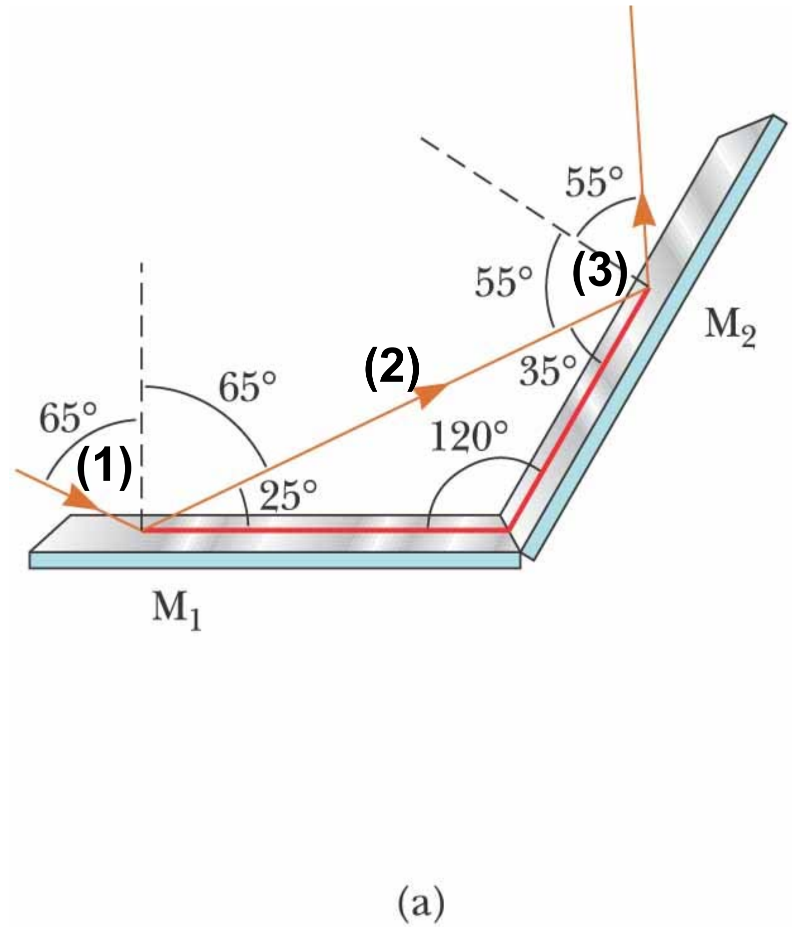


Example: Multiple Reflection

(1) The incident ray strikes the first mirror

(2) The reflected ray is directed toward the second mirror

(3) There is a second reflection from the second mirror

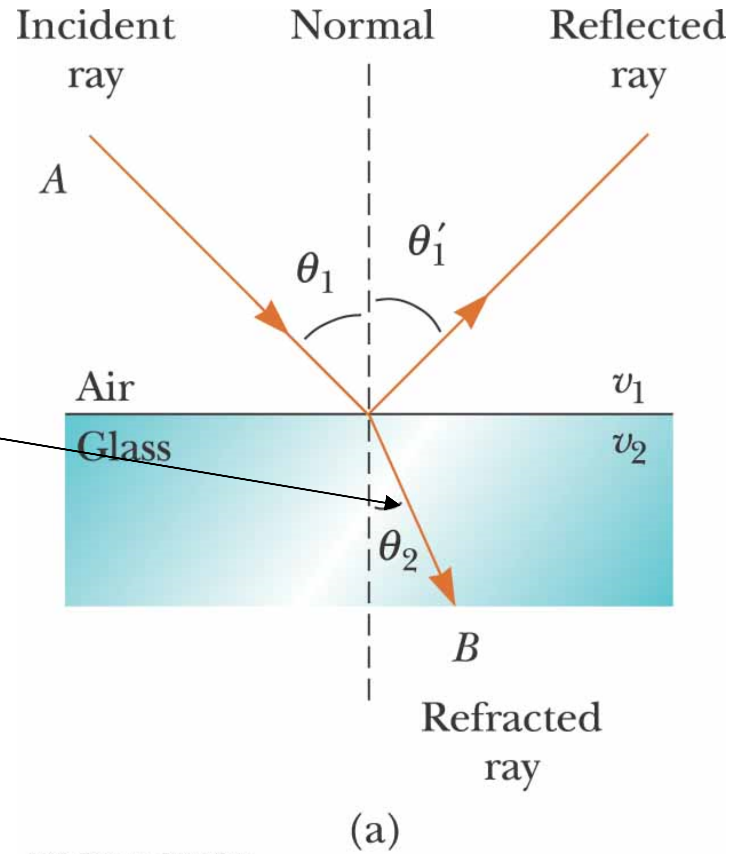


Propagation of Light - Ray Optics

What happens to light at the boundary between two media?

The light can be

- **reflected or**
- **refracted (transmitted)**

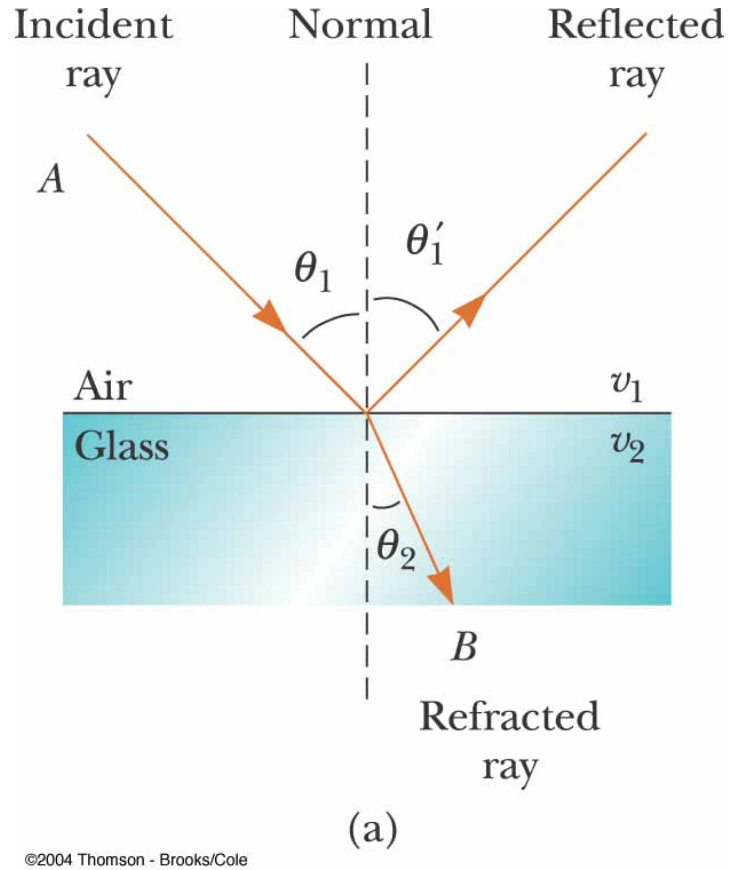


Refraction – Snell's Law

- **The incident ray, the refracted ray, and the normal all lie on the same plane**
- **The angle of refraction is related to the angle of incidence as**

$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

  - **v_1 is the speed of the light in the first medium and v_2 is its speed in the second**



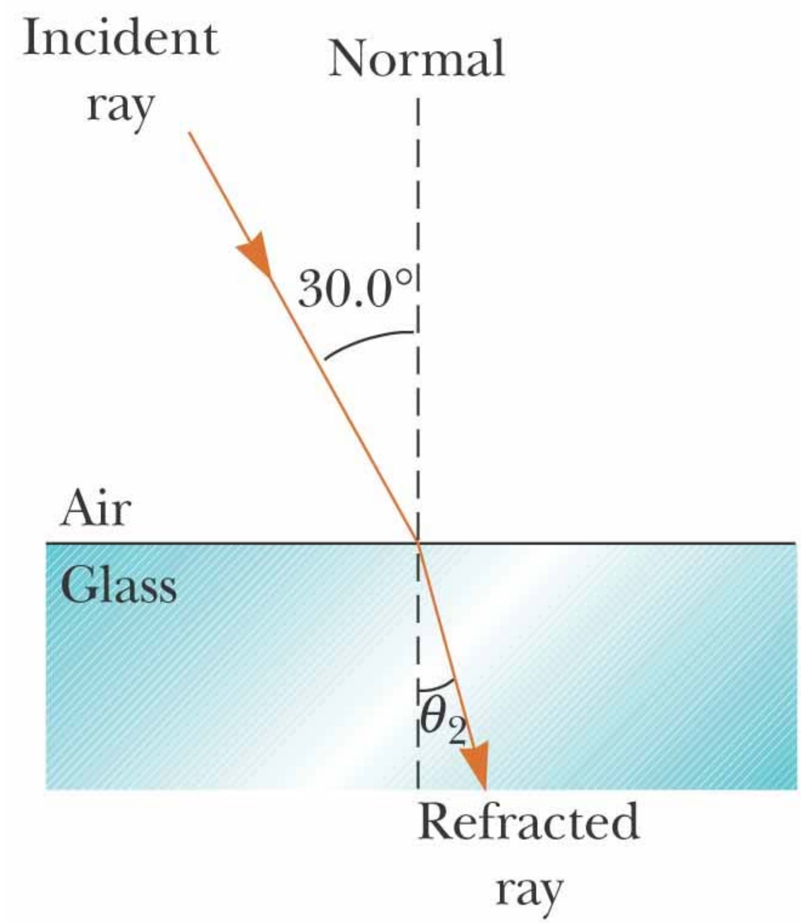
Since $v_1 = \frac{c}{n_1}$ and $v_2 = \frac{c}{n_2}$, we get $\frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1} = \frac{c/n_2}{c/n_1} = \frac{n_1}{n_2}$, or $n_2 \sin\theta_2 = n_1 \sin\theta_1$

index of refraction

Snell's Law

Snell's Law: Example

- **Light is refracted into a crown glass slab**
- $\Theta_1 = 30.0^o$, $\Theta_2 = ?$
- $n_1 = 1.0$ **and** $n_2 = 1.52$
- $n_1 \sin \Theta_1 = n_2 \sin \Theta_2$ **then**
- $\Theta_2 = \sin^{-1}[(n_1 / n_2) \sin \Theta_1] = 19.2^o$



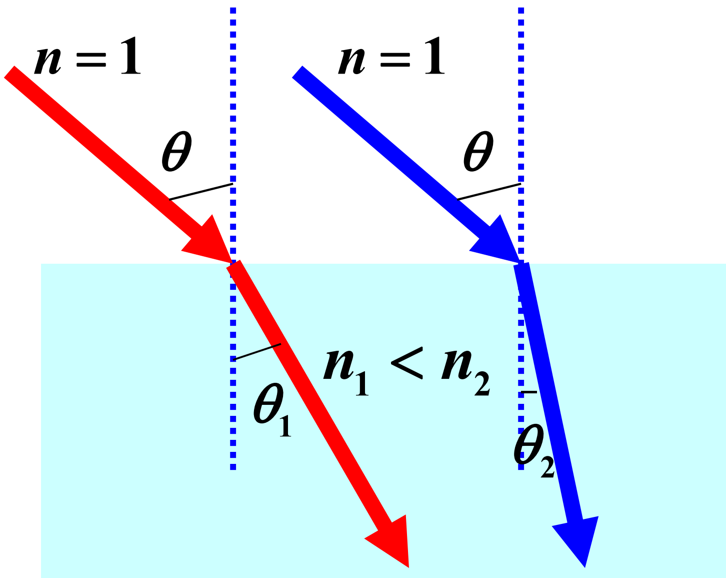
Refraction in a Prism

Variation of Index of Refraction with Wavelength

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

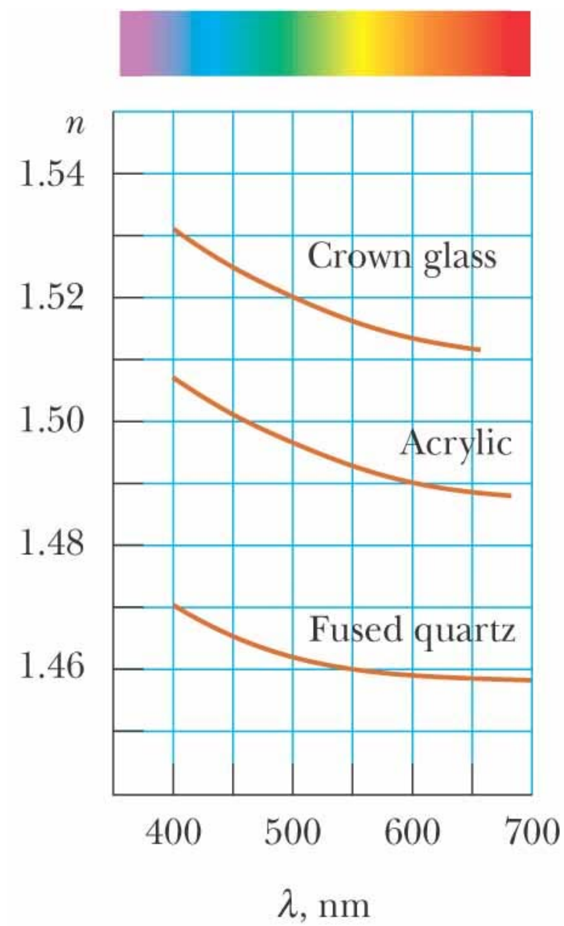
Snell's Law

- **The index of refraction depends on the wavelength (frequency)**
- **It generally decreases with increasing wavelength**



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

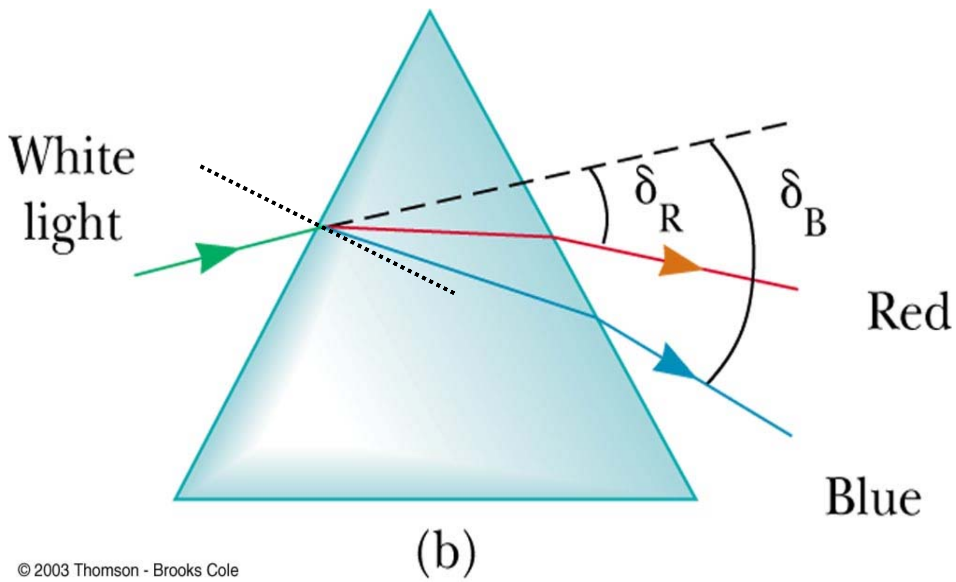
So $\theta_1 > \theta_2$

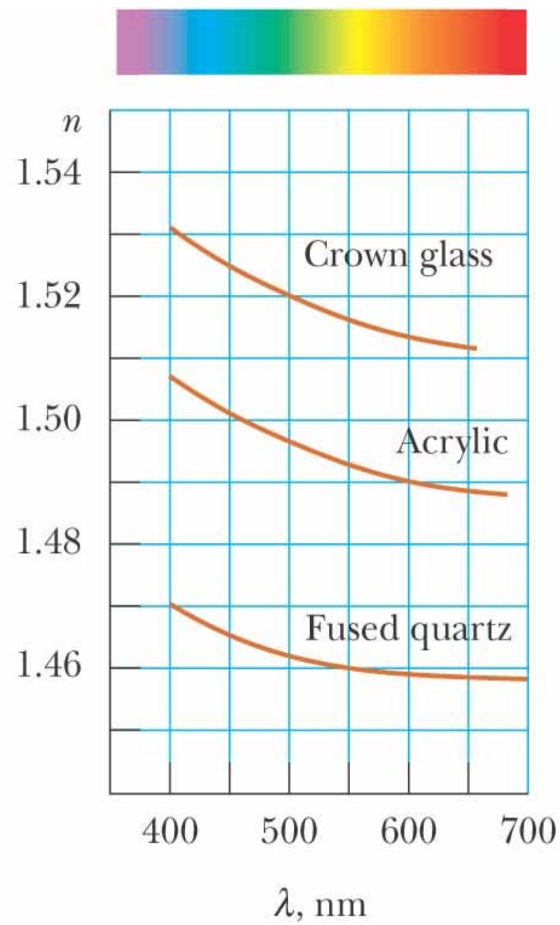


Refraction in a Prism

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

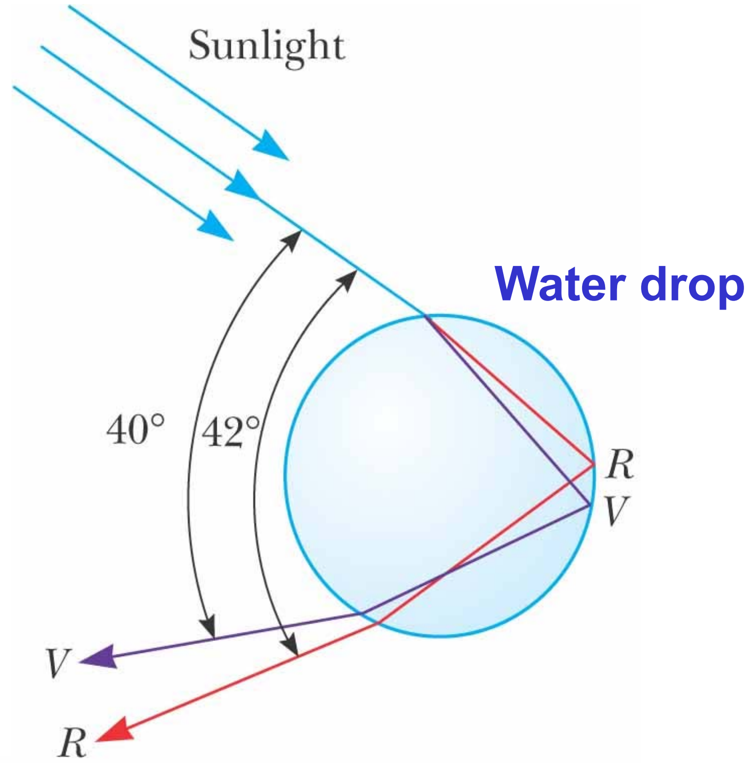
- Violet deviates the most
- Red deviates the least
- The remaining colors are in between

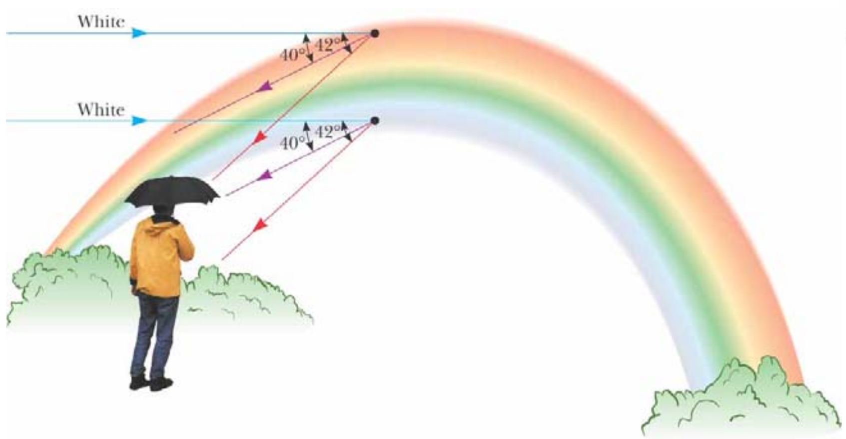




The Rainbow

- The rays leave the drop at various angles
  - The angle between the white light and the most intense violet ray is 40°
  - The angle between the white light and the most intense red ray is 42°





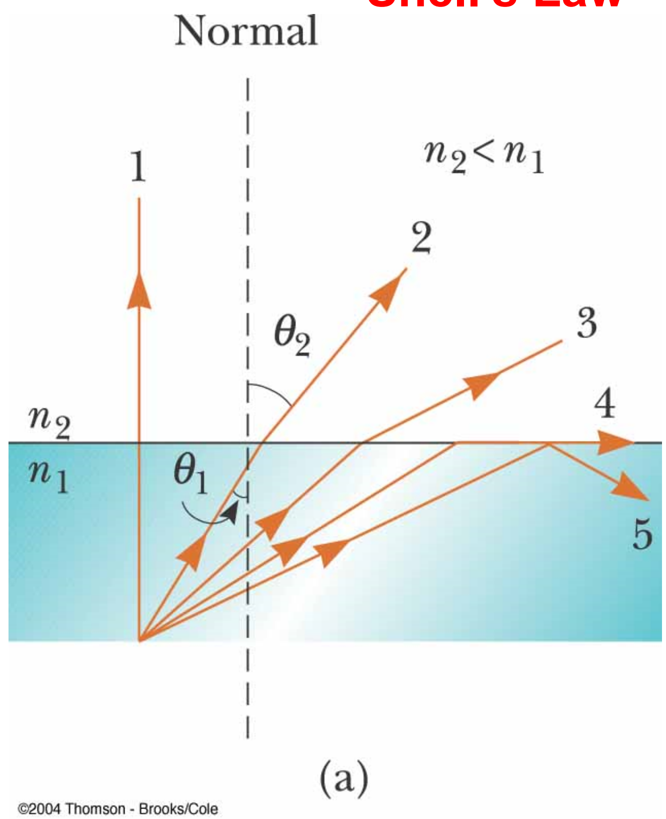
Total Internal Reflection

Possible Beam Directions: Total Internal Reflection

- Possible directions of the beam are indicated by rays numbered 1 through 5
- The refracted rays are bent away ($\theta_2 > \theta_1$) from the normal since $n_2 < n_1$
- For ray 4 we have $\theta_2 = 90^o$ the corresponding angle of incidence can be found from the condition ($\sin 90^o = 1$)

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

Snell's Law



$$n_2 = n_1 \sin\theta_{1,cr}$$

Total Internal Reflection: Critical Angle

- Critical angle:

$$n_2 = n_1 \sin\theta_{1,cr}$$

- IMPORTANT:

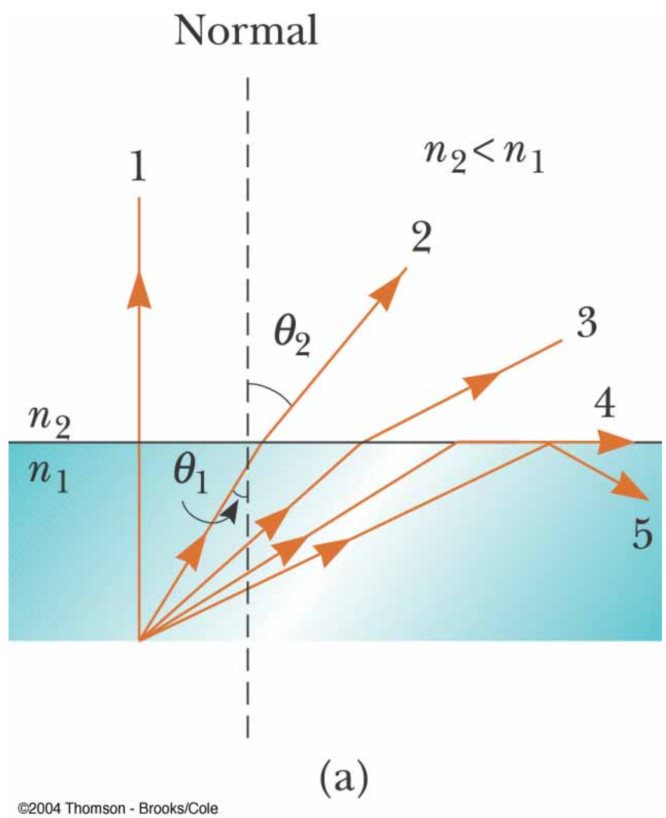
All the rays with $\theta_1 > \theta_{1,cr}$ will be totally reflected, because if $\theta_1 > \theta_{1,cr}$ then we get from Snell' Law

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 > \frac{n_1}{n_2}\sin\theta_{1,cr} = 1$$

This is impossible

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

Snell's Law

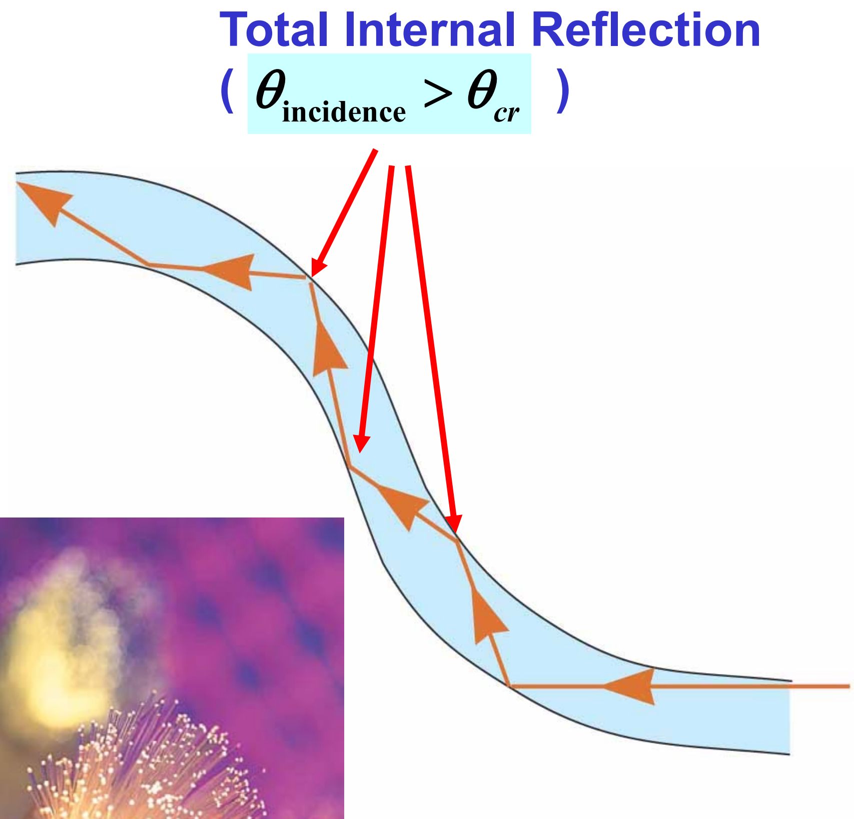


Example: What is θ_{cr} for glass-air boundary?

$n_1 = n_{glass} \approx 1.5$ $n_2 = n_{air} \approx 1$ **then** $\theta_{cr} = \sin^{-1}\frac{n_{air}}{n_{glass}} = \sin^{-1}\frac{1}{1.5} \approx 0.73$

Fiber Optics

- **Plastic or glass rods are used to "pipe" light from one place to another**
- **Applications include:**
  - **medical use of fiber optic cables for diagnosis and correction of medical problems**
  - **Telecommunications**



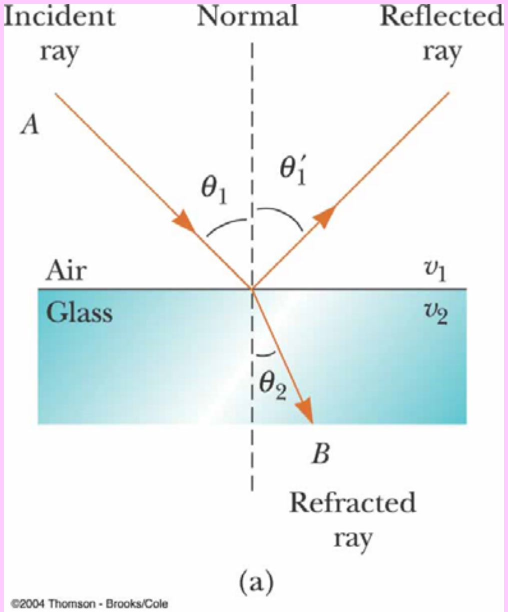
$v = \frac{c}{n}$ - The speed of light in the medium

The law of reflection:

$\theta_1 = \theta_1'$

The law of refraction:

$n_2 \sin\theta_2 = n_1 \sin\theta_1$ Snell's Law



Total Internal Reflection

$n_2 = n_1 \sin\theta_{1,cr}$