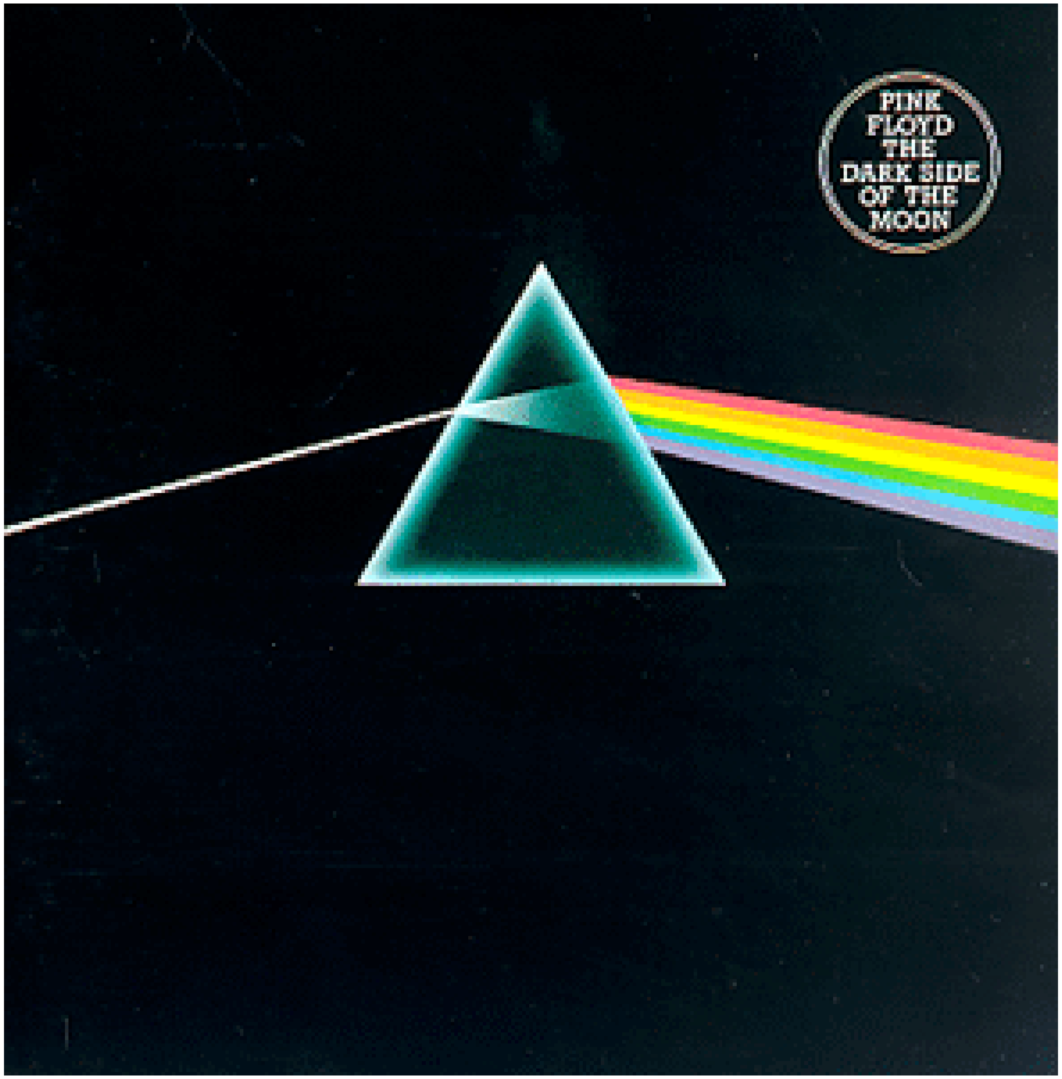
November 12th

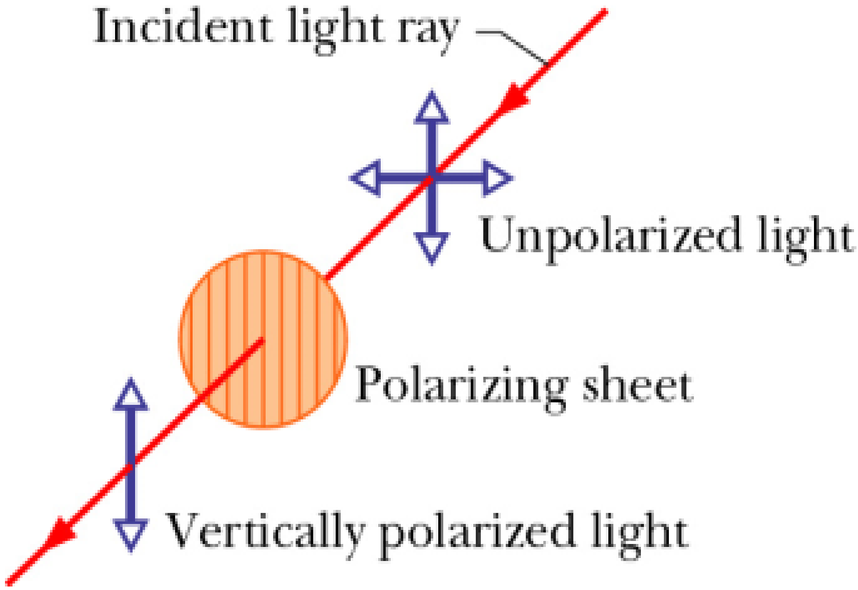
Electromagnetic Waves

Chapter 34



Review

- Waves are polarized if *E* field component of EM waves always points in same direction
- EM waves with randomly oriented *E* fields are unpolarized



- Intensity of unpolarized light after hitting a polarizing sheet

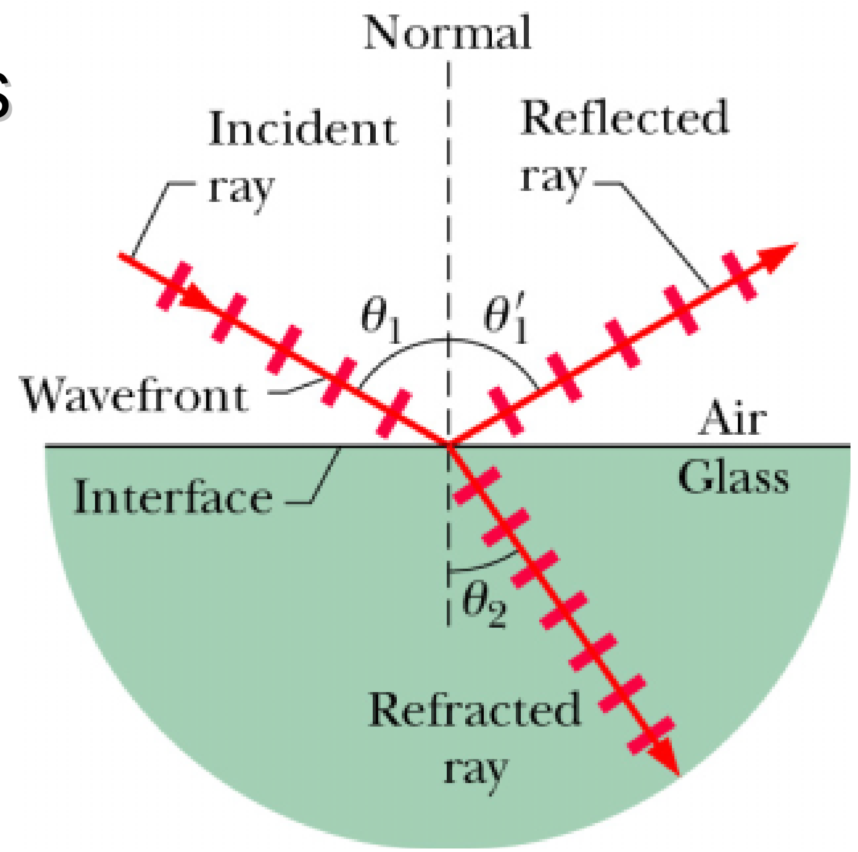
$$I = \tfrac{1}{2} I_0$$

- Intensity of polarized light after hitting a polarizing sheet

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

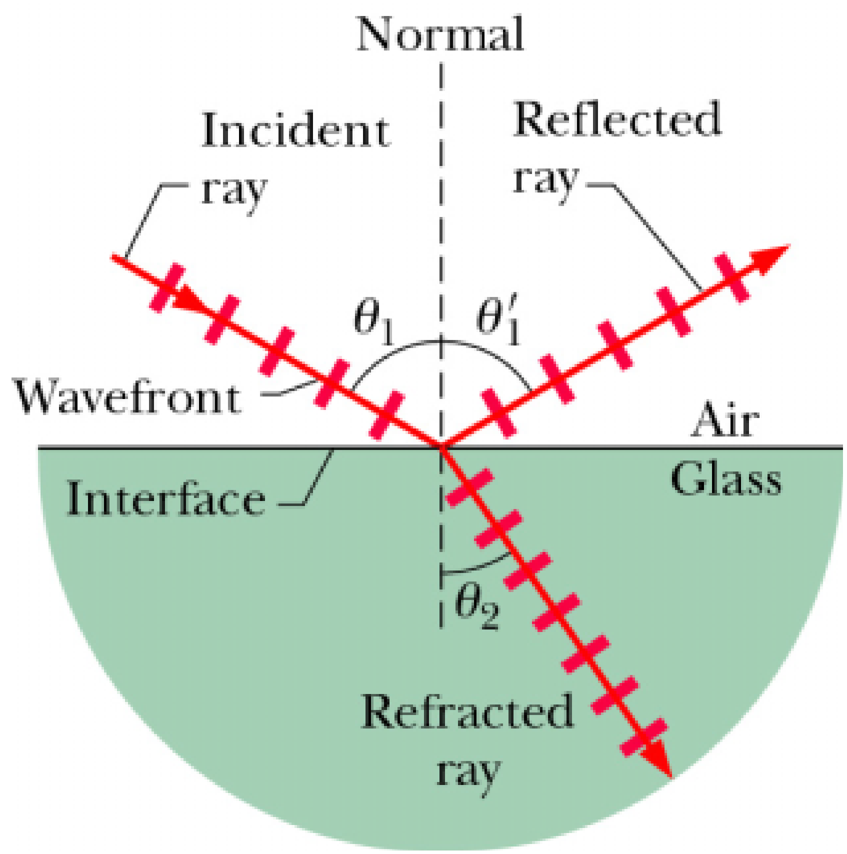
Reflection & Refraction (Fig. 34-17)

- Represent light waves as straight lines or rays
- If incident (incoming) light wave hits surface of different material some light will
  - Be reflected back
  - Travel through and be refracted



Reflection & Refraction (Fig. 34-17)

- Define a line, the normal, which is ⊥ to surface at point where the incident beam hits the surface
- Angles relative to normal
  - Angle of incidence θ_1
  - Angle of reflection θ_1'
  - Angle of refraction θ_2
- Plane containing incident ray and normal is plane of incidence



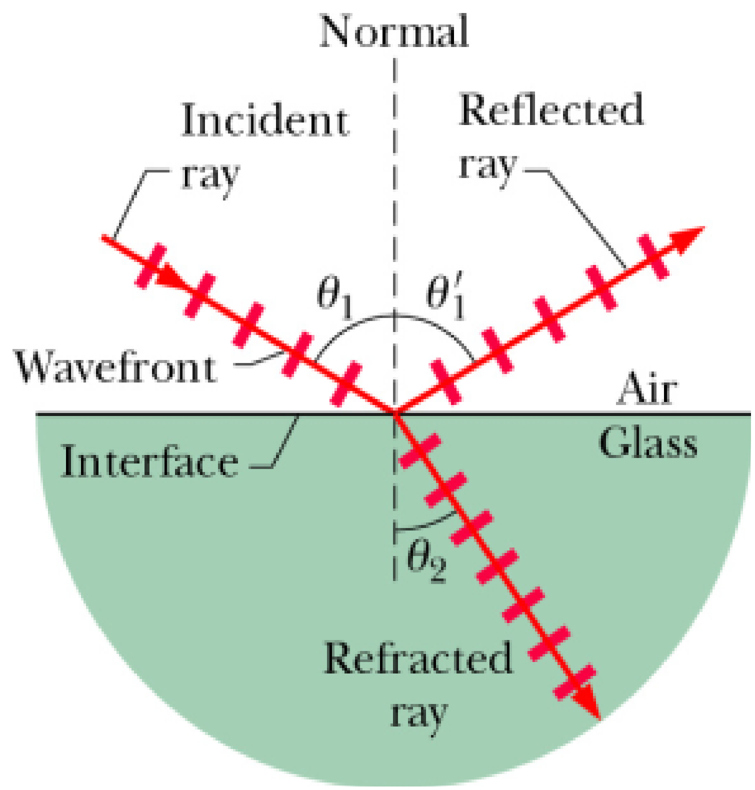
Reflection & Refraction (Fig. 34-17)

- Law of reflection: Reflected ray lies in plane of incidence and angle for reflection is equal to angle of incidence

$$\theta_1' = \theta_1$$

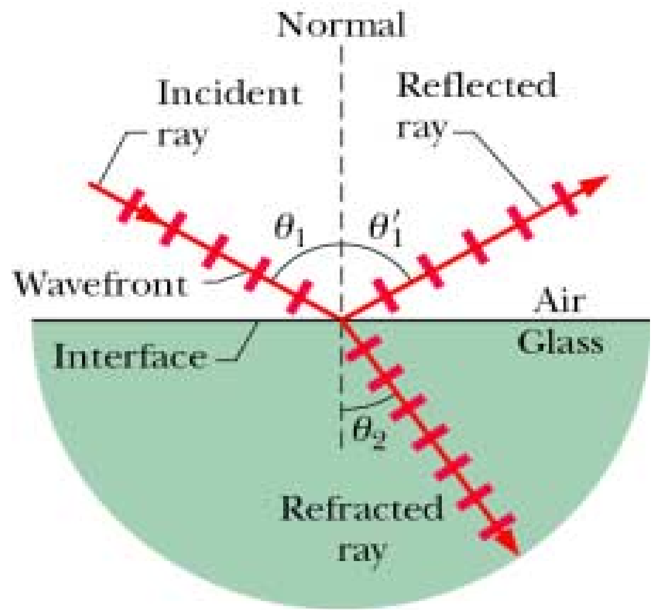
- Law of refraction: Refracted ray lies in plane of incidence and angle of refraction is related to angle of incidence by Snell's law

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



Reflection & Refraction (Fig. 34-17)

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



- *n* is dimensionless constant called index of refraction
- Index of refraction, *n* for given medium is defined as

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}} = \frac{c}{v}$$

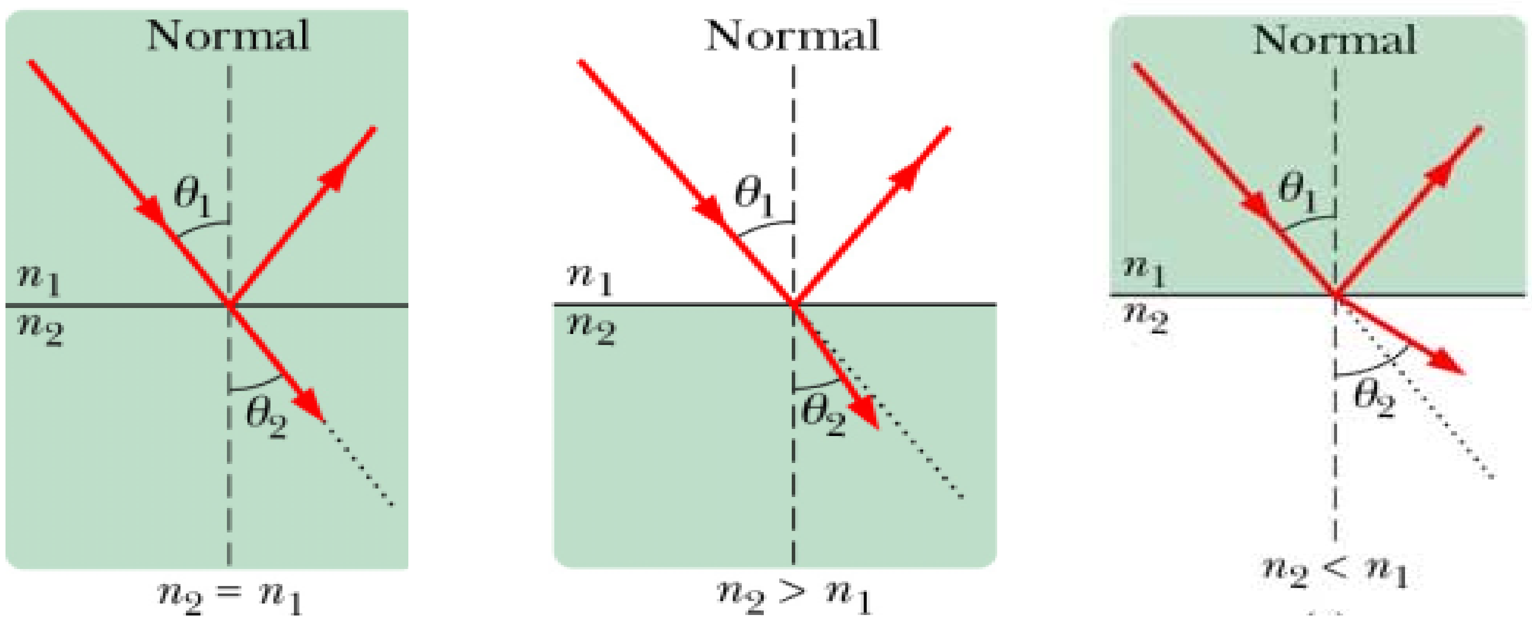
- Nothing has $n < 1$, velocity of wave in medium is always less than the speed of light

Medium	Index, n
Vacuum	Exactly 1
Air	1.00029
Glass	1.52
Diamond	2.42
Water	1.33

Reflection & Refraction (Fig. 34-18)

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

$n_2 = n_1$	$n_2 > n_1$	$n_2 < n_1$
$\theta_2 = \theta_1$	$\theta_2 < \theta_1$	$\theta_2 > \theta_1$



Reflection & Refraction (Fig. 34-18)

- Traveling from one medium to another
  - Frequency of wave does not change.
  - Thus the "color" does not change (when our eye sees "red" it is the frequency associated with red which is important).
  - Wavelength and velocity do change

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

$$v_1 = \lambda_1 f$$

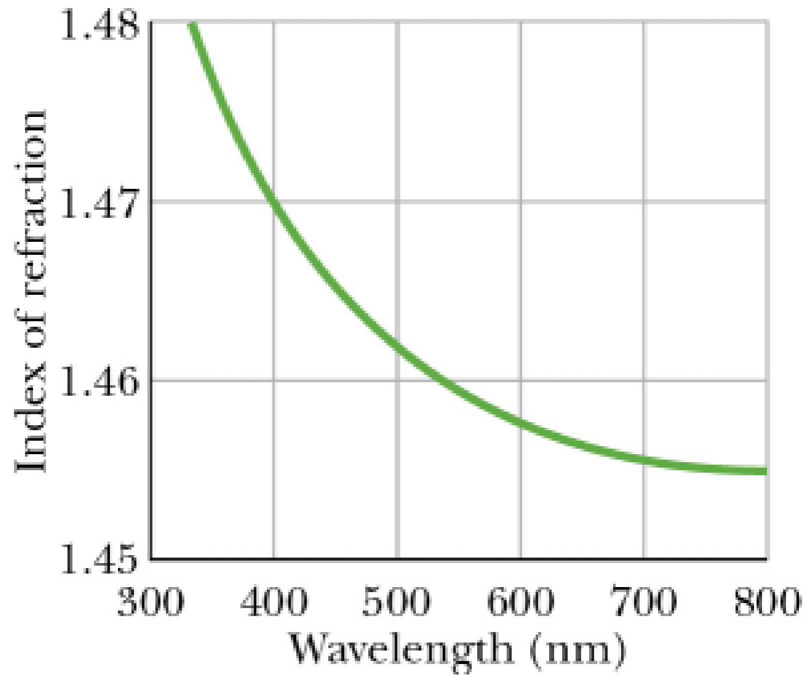
$$v_2 = \lambda_2 f$$

$$\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{c/n_1}{c/n_2} = \frac{n_2}{n_1}$$

Dispersion (Fig. 34-19)

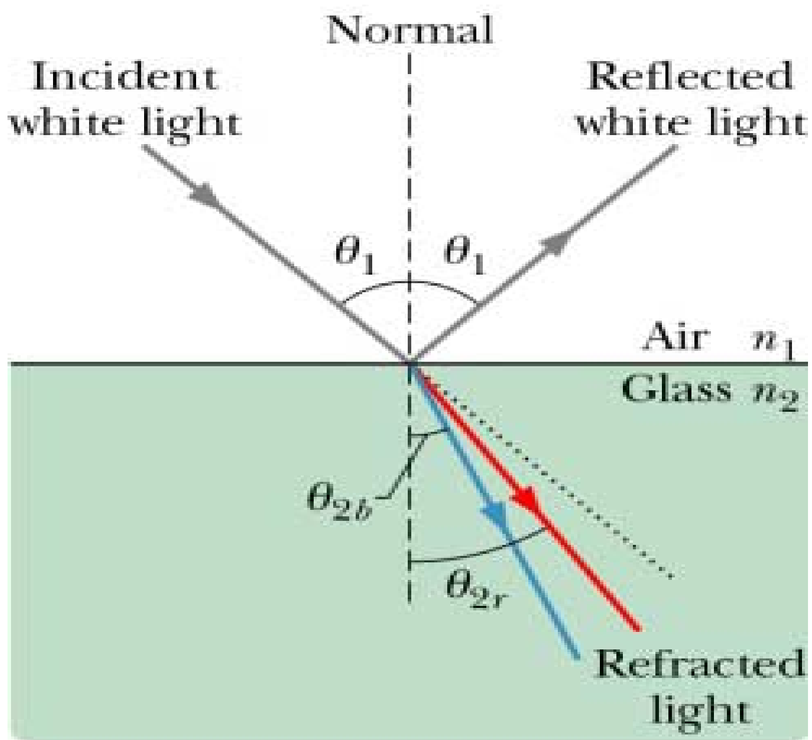
- *n* depends on wavelength of light, except in vacuum
- Beam consists of different wavelengths, rays are refracted at different angles and spread out – chromatic dispersion
- White light consists of components of all the colors in visible spectrum with uniform intensities

Fused quartz

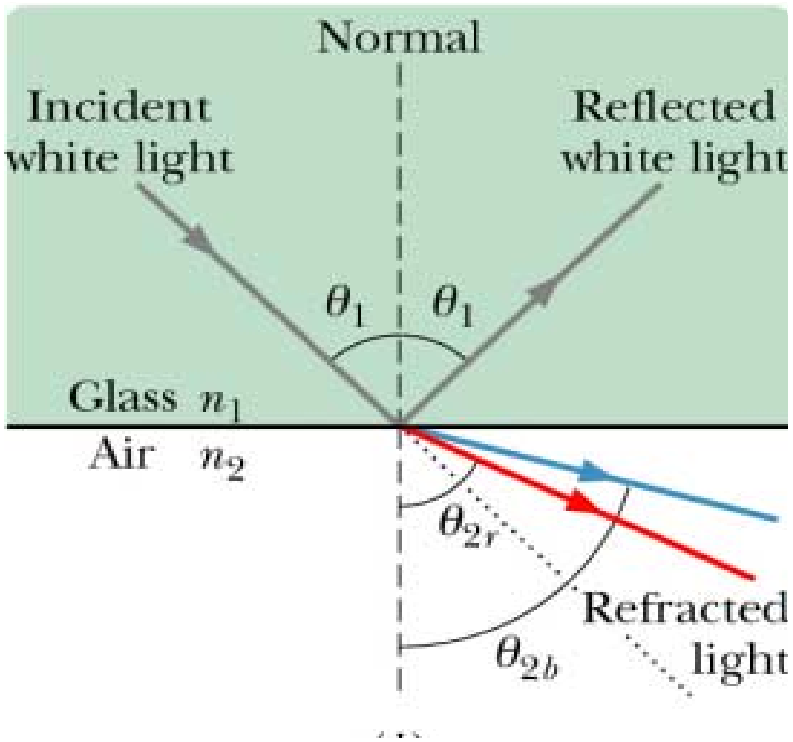


Dispersion (Fig. 34-20)

- n for a medium is greater for shorter wavelengths (blue) than for longer (red)
- Blue light is bent more than red light

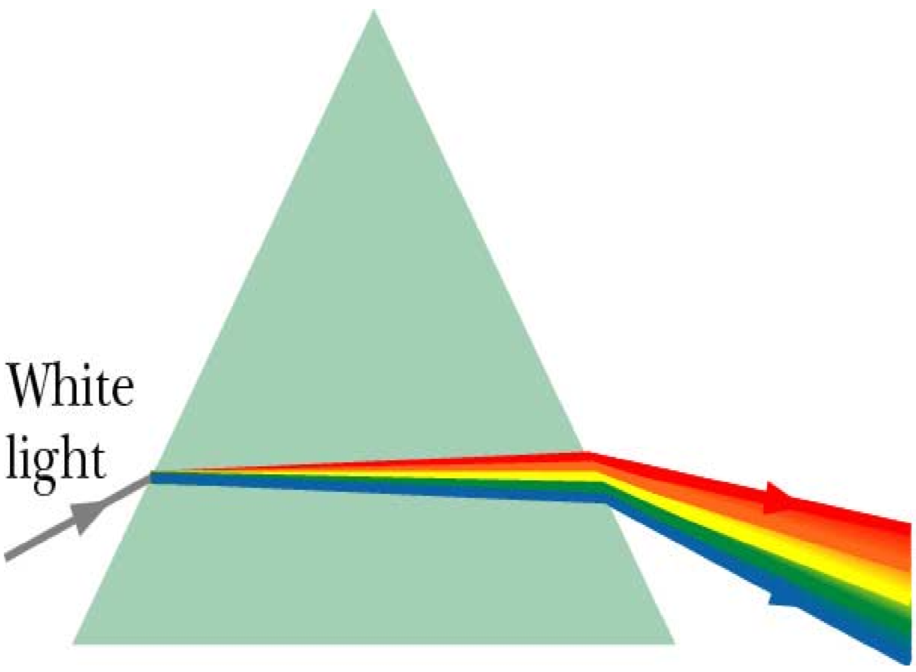


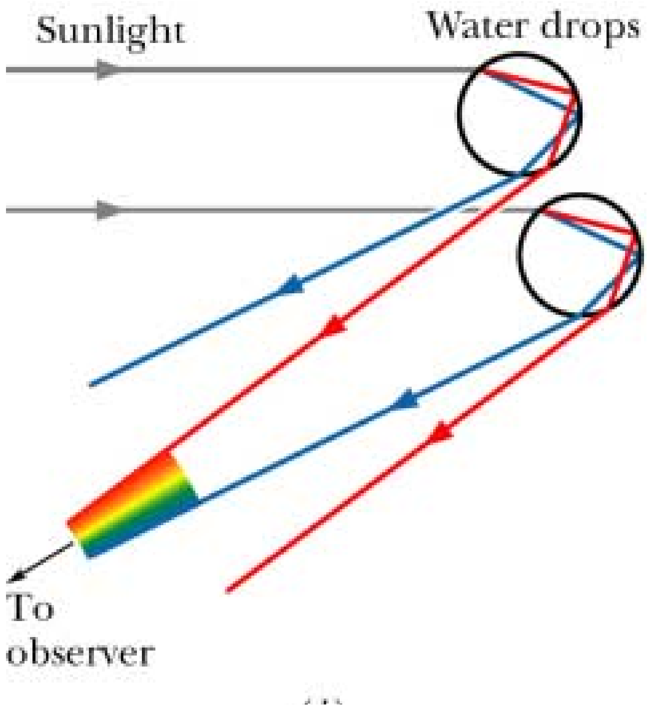
Dispersion (Fig. 34-20)



Dispersion (Figs. 34-21, 34-22)

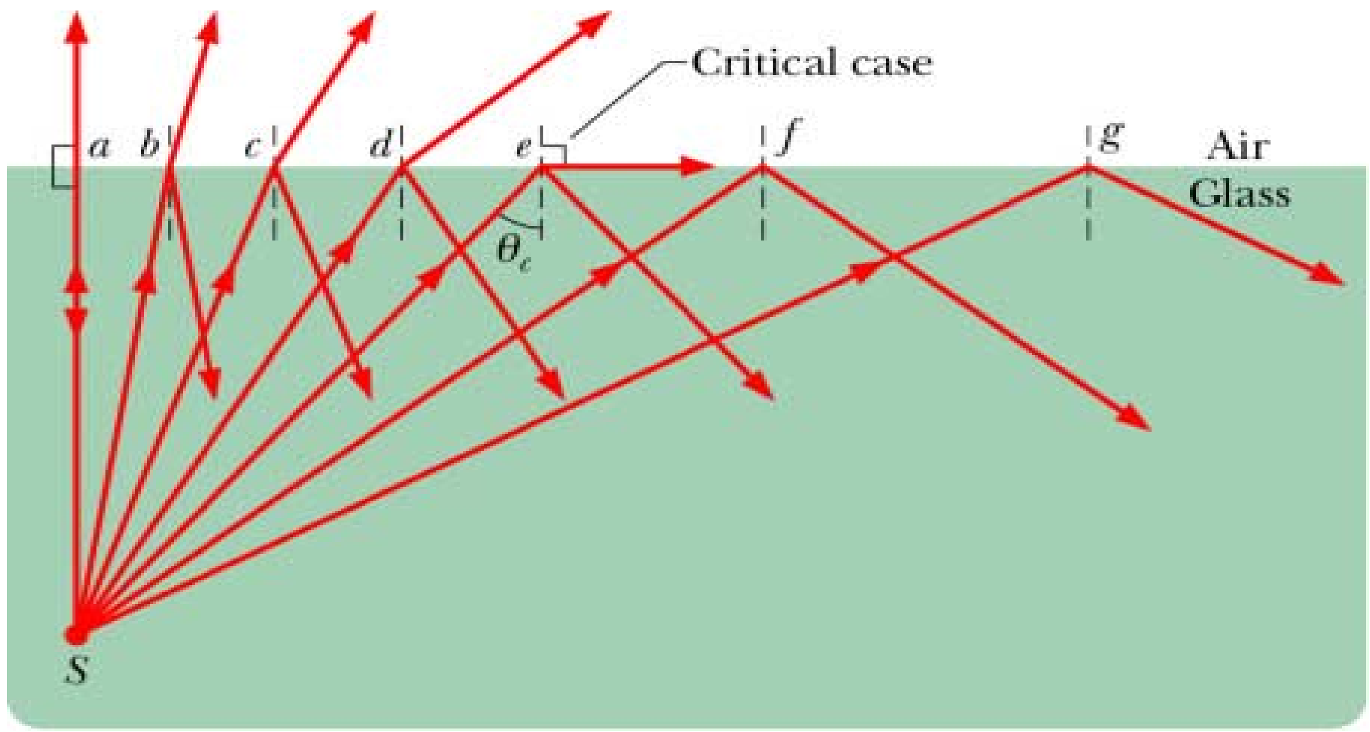
- Examples of chromatic dispersion
  - White light through a prism
  - Rainbow





Internal reflection (Fig. 34-24)

- The angle of incidence which causes the refracted ray to point directly along the surface is called the critical angle, θ_c
- Angles larger than θ_c no light is refracted so have total internal reflection



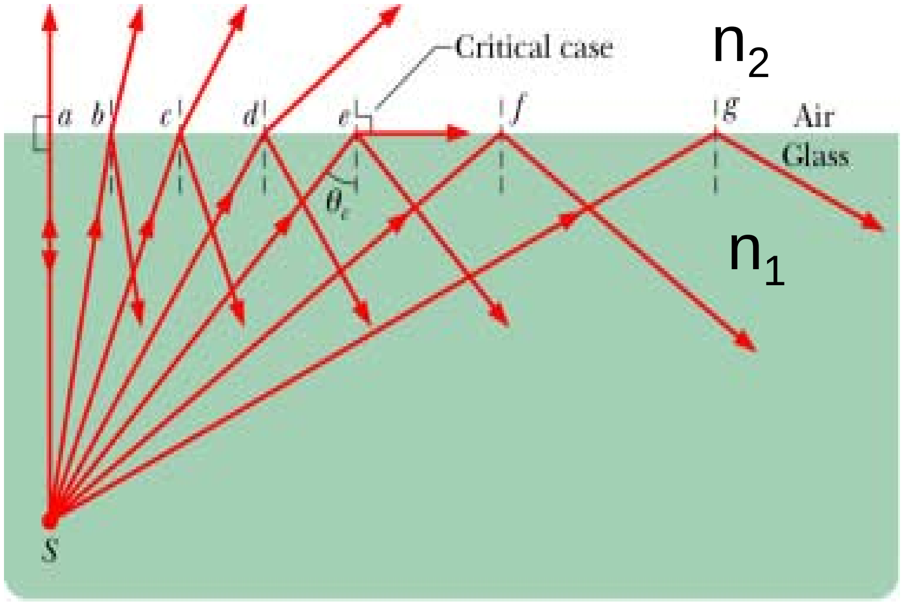
Internal reflection (Fig. 34-24)

- Find critical angle from Snell's law where incident ray is moving from medium with n_1 to n_2

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

$$n_1 \sin\theta_C = n_2 \sin 90$$

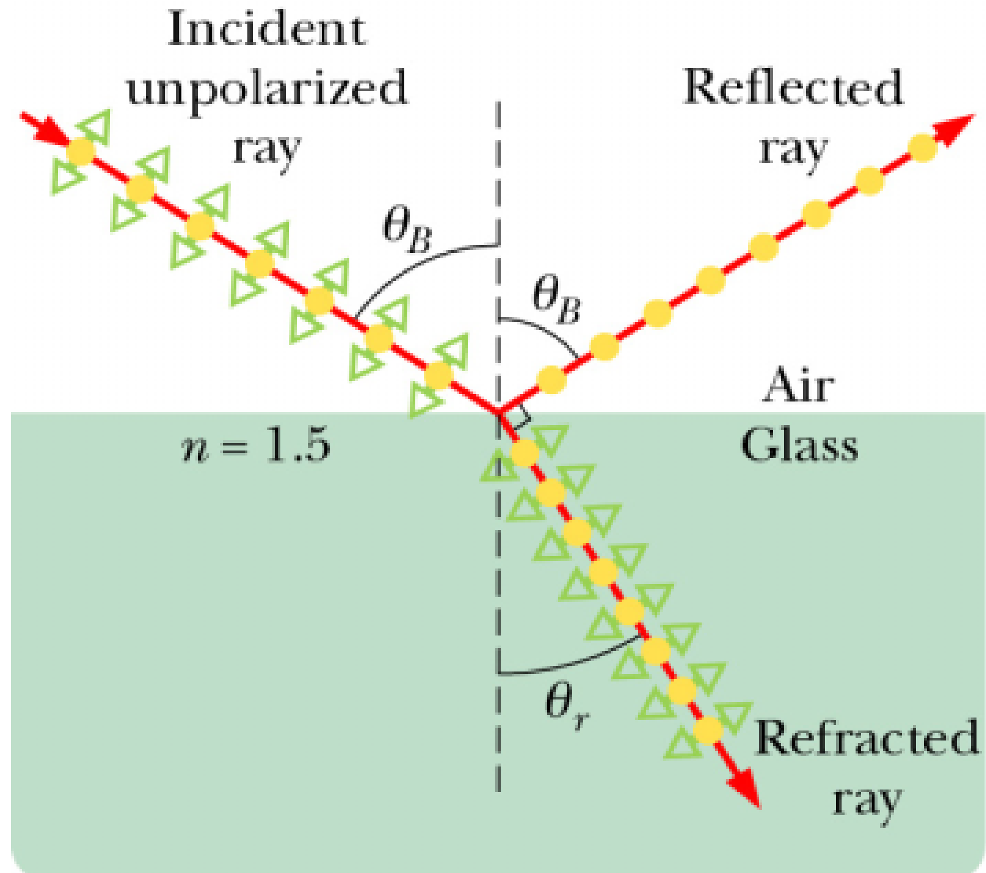
$$\theta_C = \sin^{-1}\frac{n_2}{n_1}$$



- For total internal reflection to occur $n_2 < n_1$
  - E.g. moving from water into air
  - Will not happen if moving from air into water

Polarization by reflection (Fig. 34-27)

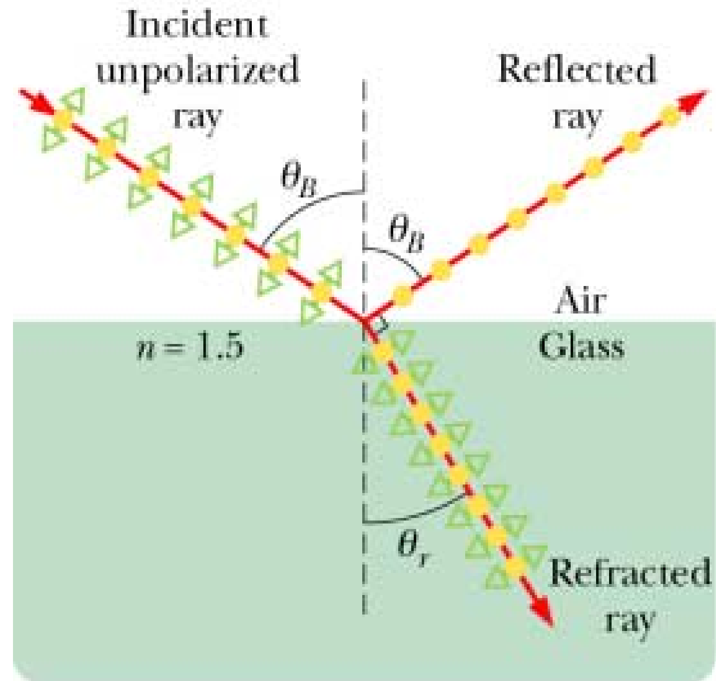
- Reflected light is partially polarized
- When the light is incident at the Brewster angle its reflected light is fully polarized ⊥ to the plane of incident
- Refracted light is still unpolarized



Polarization by reflection (Fig. 34-27)

- Found experimentally that reflected and refracted rays at the Brewster angle are ⊥ to each other

$$\theta_B + \theta_r = 90$$



- From the general result

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

- We find the Brewster angle

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

$$\theta_B = \tan^{-1}\frac{n_2}{n_1}$$