Recap

Lecture 28

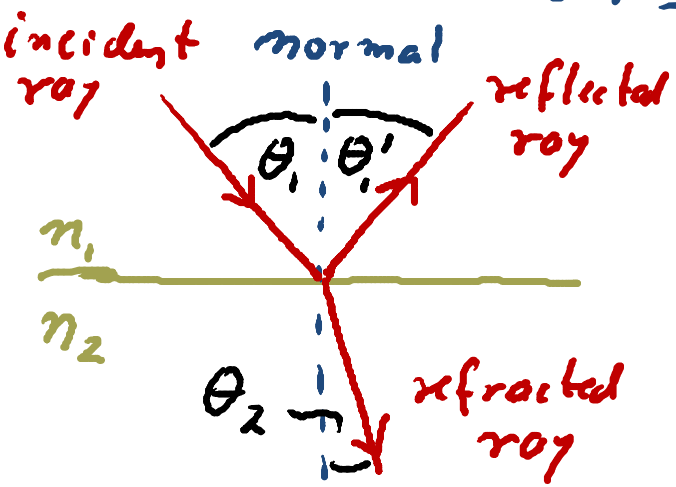
- **Geometrical Optics:**
  - Valid for (1) Light beams with width $\gg \lambda_{light}$
  - (2) Objects with size $\gg \lambda_{light}$

  $\Rightarrow$ Light travels in straight lines (rays) through vacuum and homogeneous materials

- **Speed of Light:**

  in a material: $v_{light} = \frac{c}{n}$ ← speed of light in vacuum: $c = 3.0 \cdot 10^8$ m/s; n ← index of refraction; $n \geq 1$

- **Reflection and Refraction:**



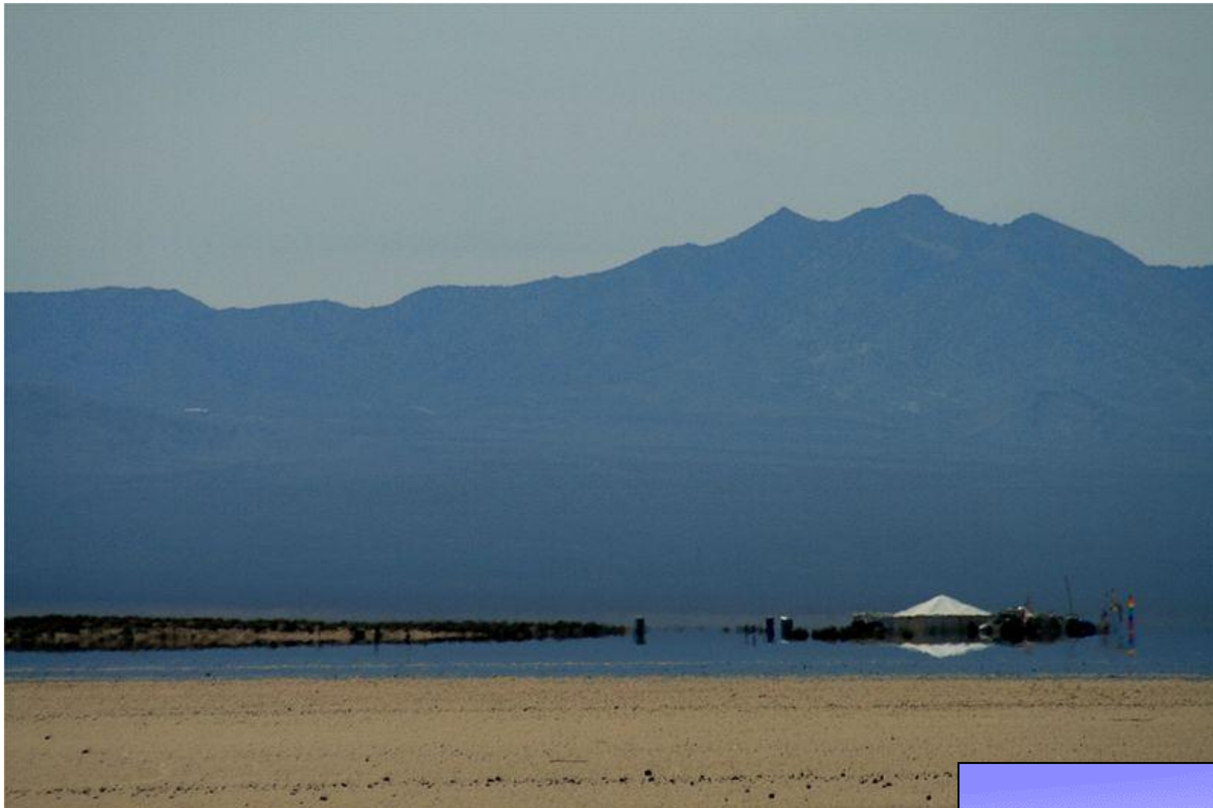
- Law of Reflection: $\theta_1' = \theta_1$
- Law of Refraction: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ (Snell's Law)
- Note: all angles are relative to the normal!

Today:

- Reflection and Refraction
    - Polarization
    - Chromatic dispersion
    - Rainbows
- Images

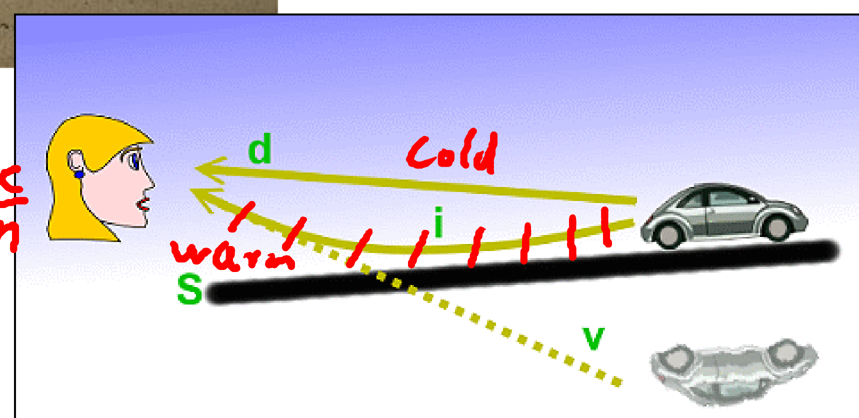
An inferior mirage on the Mojave Desert

(image seen is under the real object)

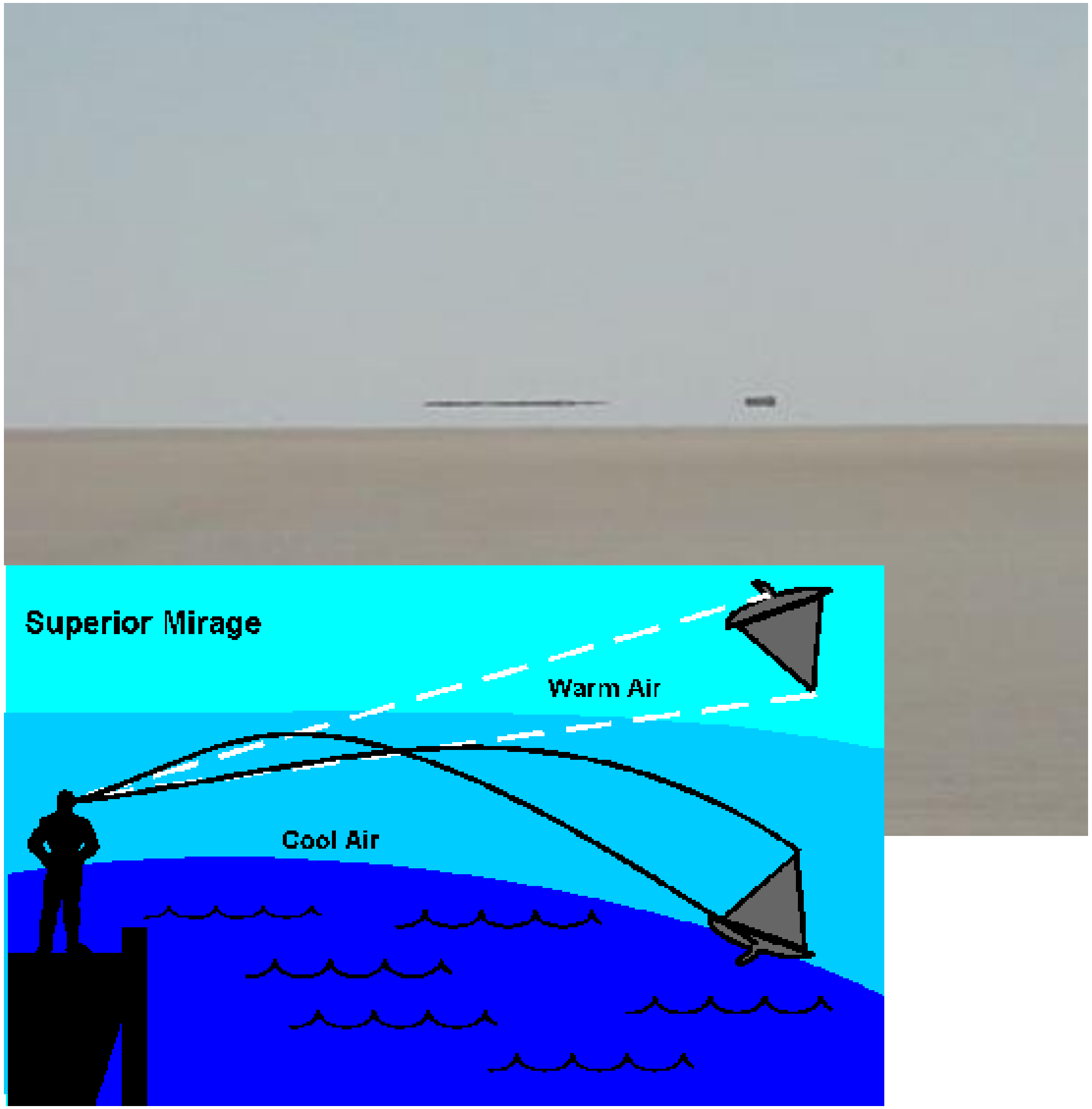


- A inferior mirage occurs when the air near the ground is much warmer than the air above
- In this case the light rays are bent up and so the image appears below the true object

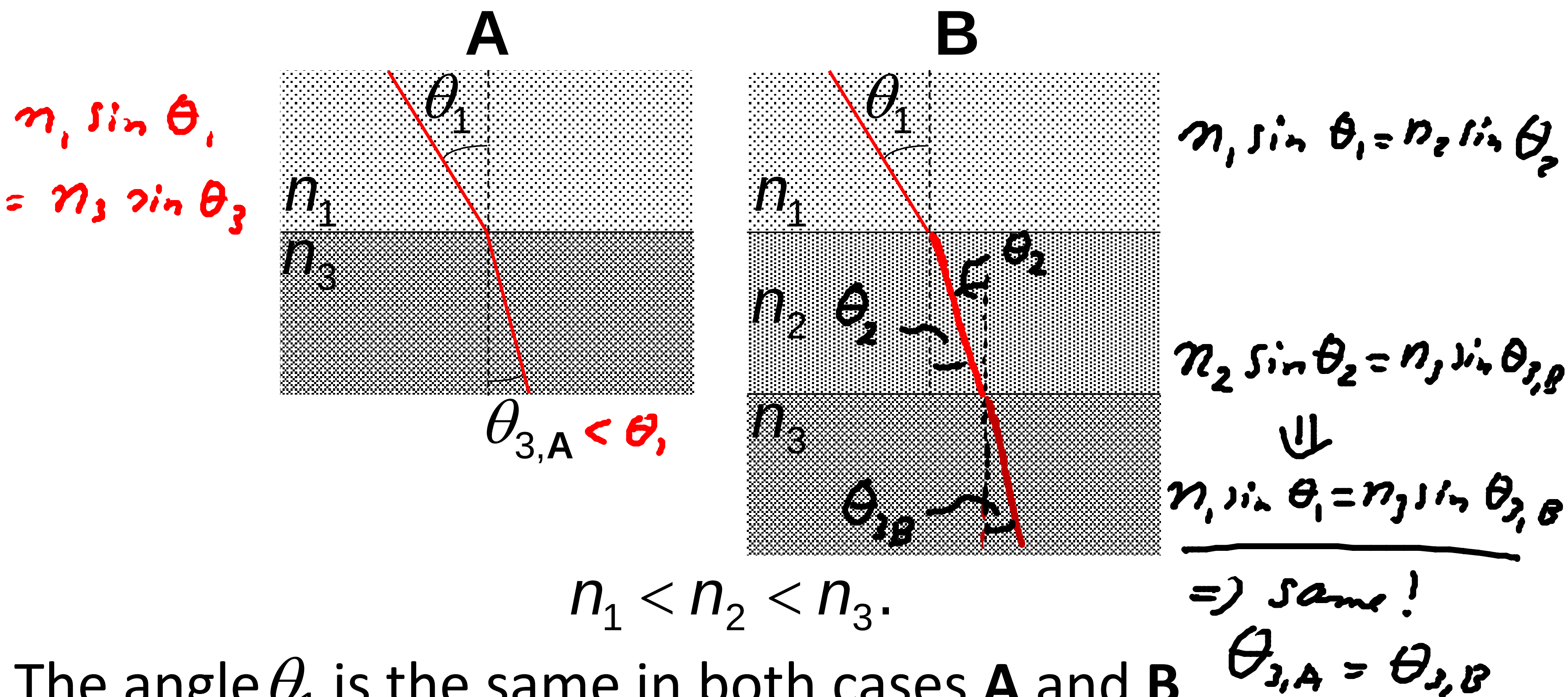
higher T ⇒ lower density
⇒ lower n ⇒ higher $v_{wave} = \frac{c}{n}$



An superior mirage
(image seen is above the real object)



- A superior mirage occurs when the air below the line of sight is colder than that above (temperature inversion)
- In this case the light rays are bent down and so the image appears above the true object



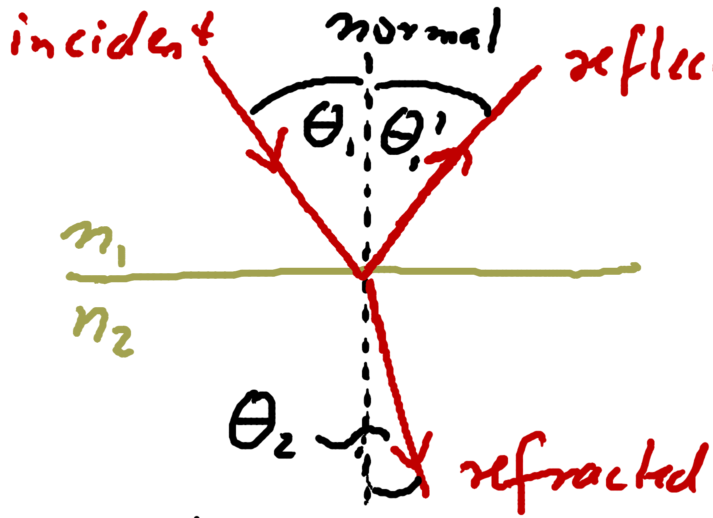
$$n_1 < n_2 < n_3.$$

The angle θ_1 is the same in both cases **A** and **B**. For case **B**, how does the angle $\theta_{3,\mathbf{B}}$ that the ray makes with a normal to the interfaces when it's in the medium with refractive index n_3 compare with $\theta_{3,\mathbf{A}}$?

A. $\theta_{3,\mathbf{B}} < \theta_{3,\mathbf{A}}$ B. $\theta_{3,\mathbf{B}} = \theta_{3,\mathbf{A}}$ C. $\theta_{3,\mathbf{B}} > \theta_{3,\mathbf{A}}$

D. It depends on the thickness of medium 2.

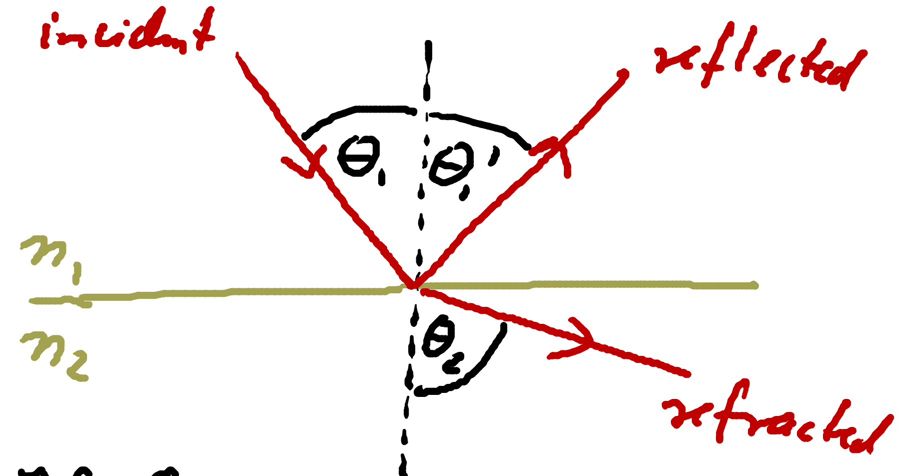
if $n_2 > n_1 \Rightarrow \theta_2 < \theta_1$



$$\theta_1' = \theta_1$$

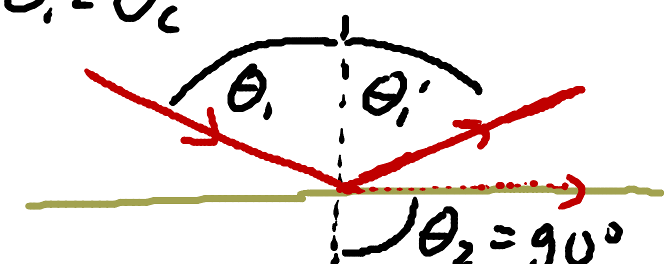
$$\sin\theta_2 = \underbrace{\frac{n_1}{n_2}}_{<1 \text{ here}} \sin\theta_1$$

if $n_2 < n_1 \Rightarrow \theta_2 > \theta_1$



$\Rightarrow$ If θ_1 is increased, eventually $\theta_2 \to 90°$:

at: $\theta_1 = \theta_c$

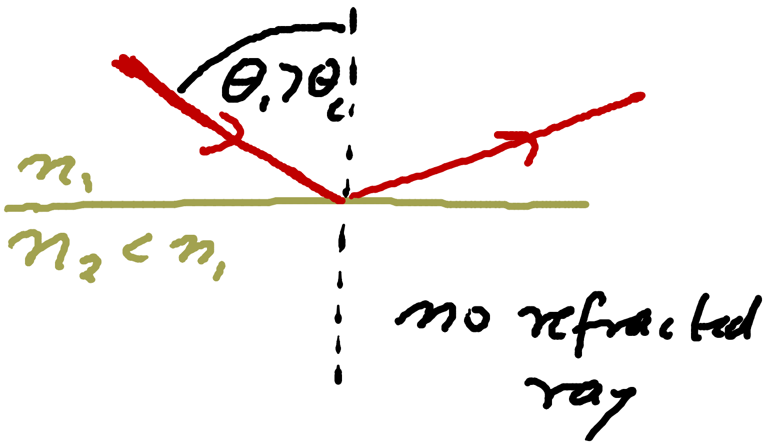


$\sin 90° = \sin\theta_2 = 1$

This value of θ_1 is called the critical angle:

$$\boxed{\sin\theta_c = n_2/n_1}$$

$\Rightarrow$ for $\theta_1 > \theta_c$: No refracted ray!



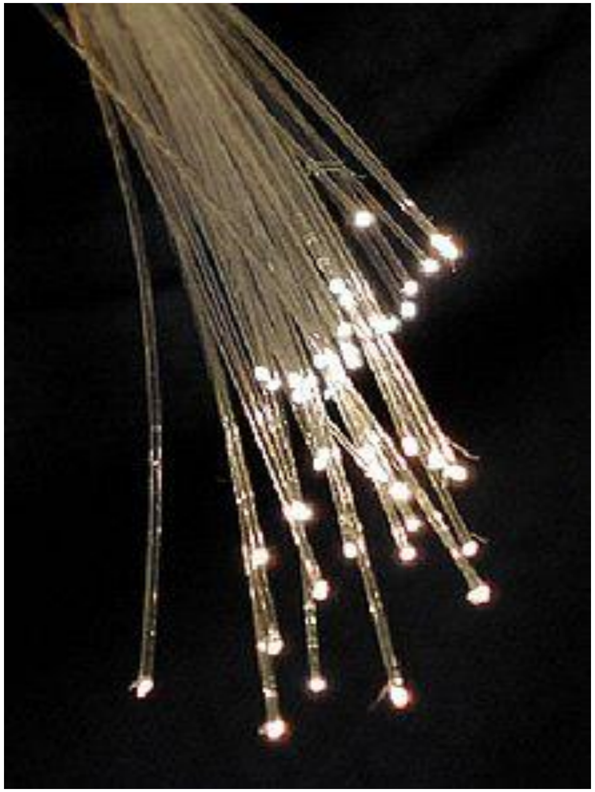
$\Rightarrow$ all incident light is reflected!

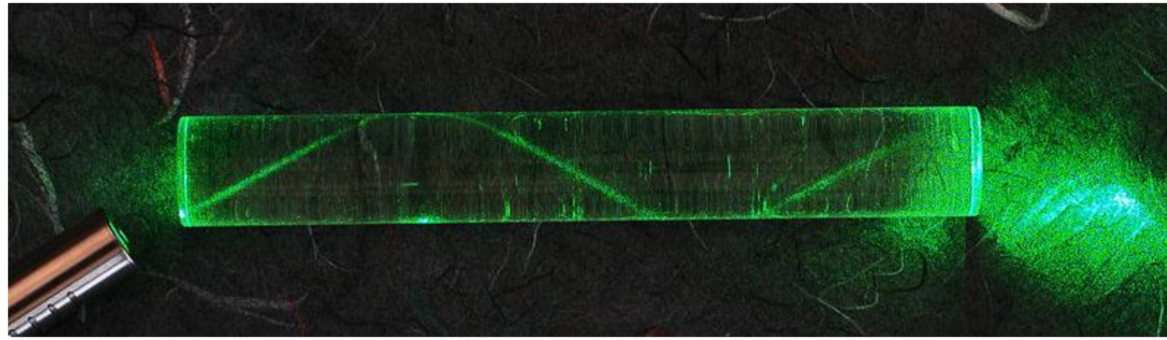
"Total internal reflection"

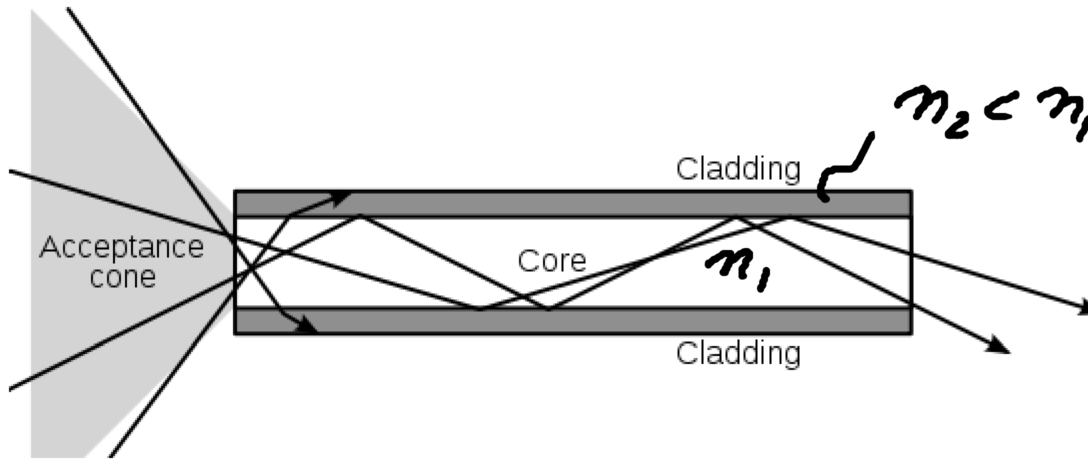
for $\theta_1 > \theta_c = \arcsin\left(\frac{n_2}{n_1}\right)$

(only for case where $n_2 < n_1$, so $\frac{n_2}{n_1} < 1$)

Application of total internal reflection: Optical fibers



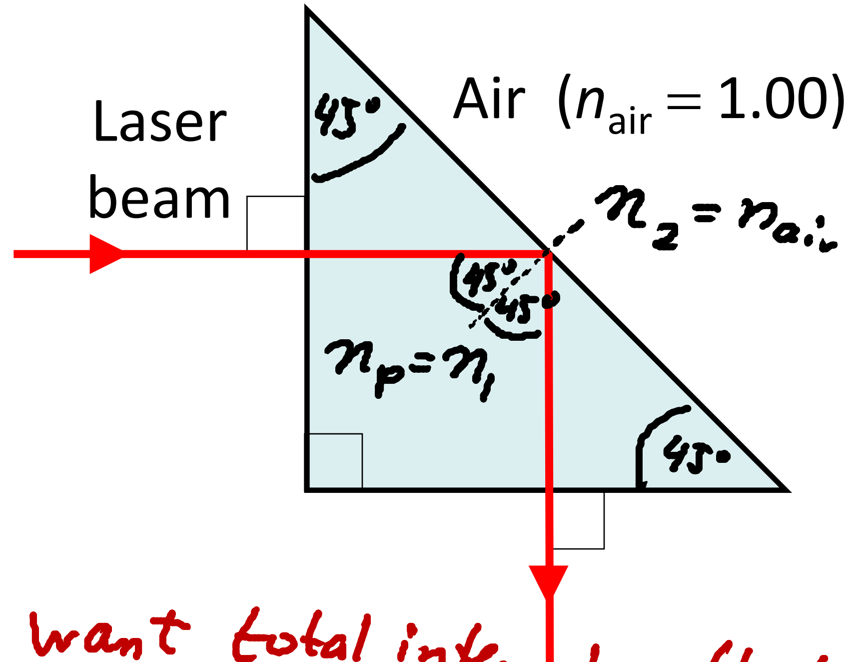




Optical fibers typically include a transparent core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by total internal reflection. This causes the fiber to act as a waveguide.

A right-angle isosceles prism can be used to redirect a high-power laser beam that would destroy a normal silvered mirror.

As shown in the figure, the beam enters the prism normal to one of its equal sides. In order for this to work, the refractive index of the prism must be greater than a particular value. What is this value?



want total internal reflection

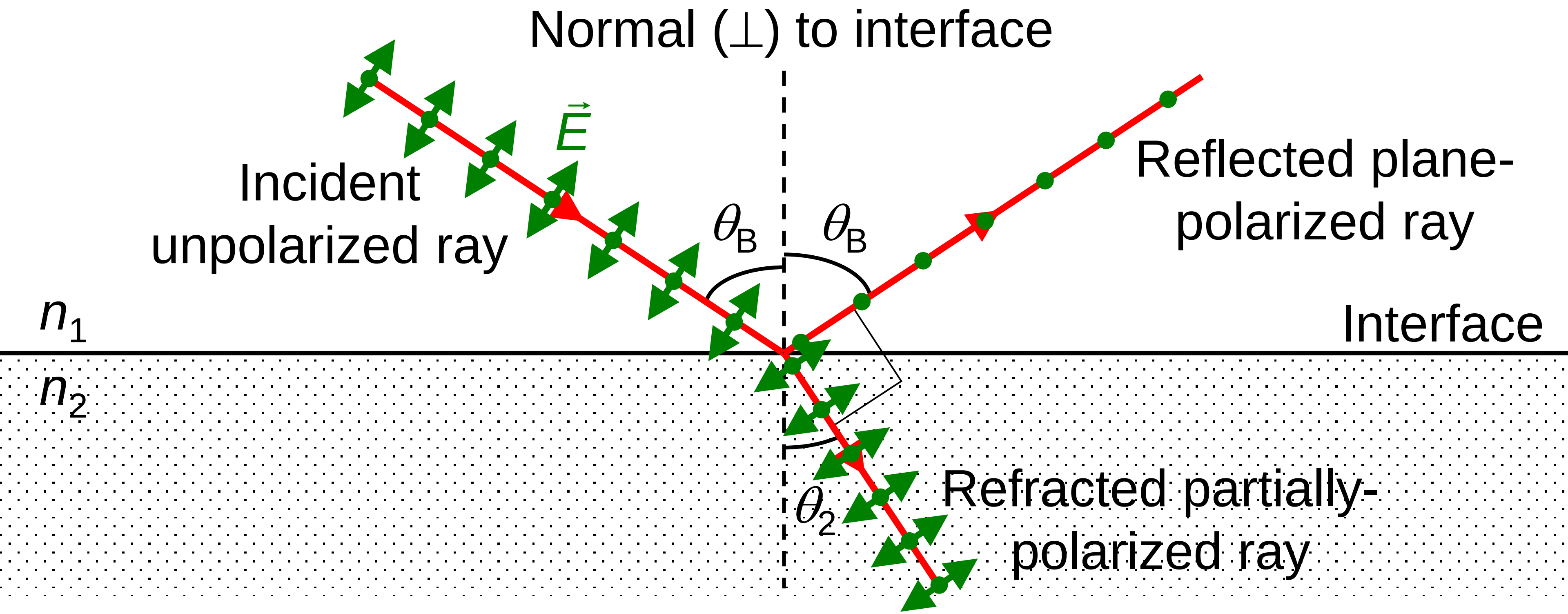
$\Rightarrow$ need: $\theta_c = \arcsin\left(\frac{n_{air}}{n_p}\right) < 45°$

$\Rightarrow$ need: $\frac{n_{air}}{n_p} < \sin 45°$

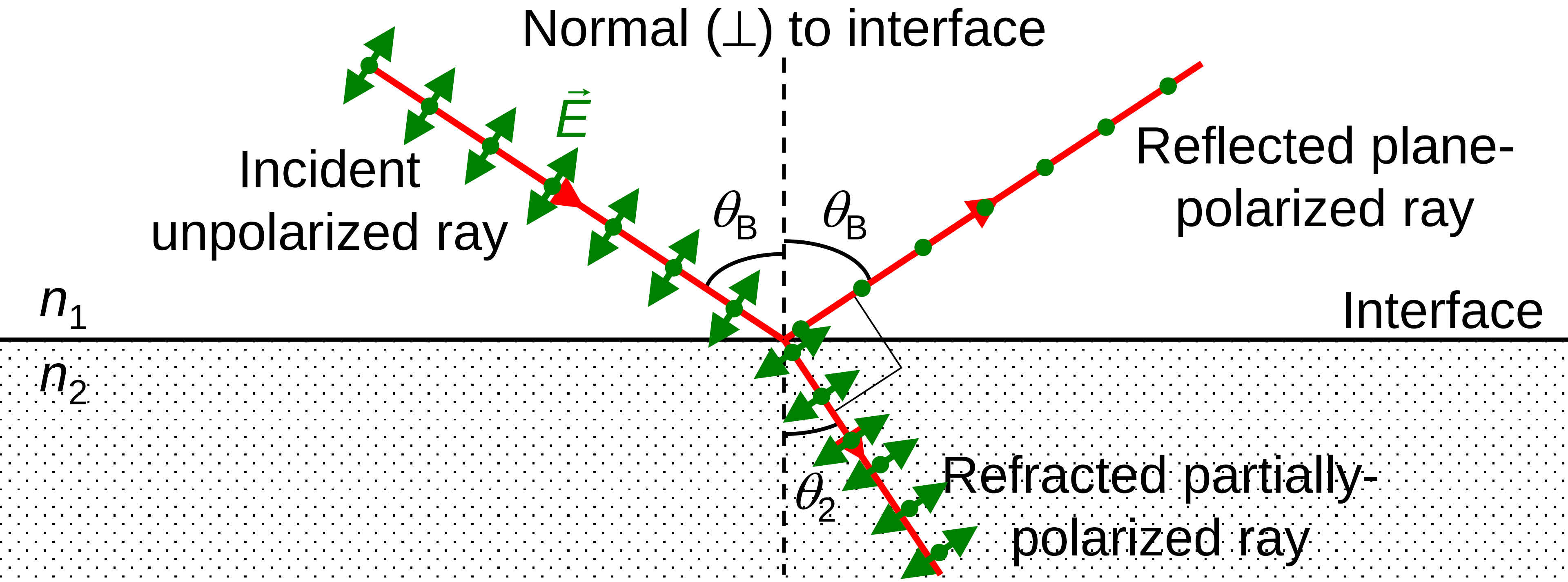
$\Rightarrow n_{prism} > n_{air}/\sin 45° = \sqrt{2}$
$= 1.41$

A. 2.00. B. 1.73. C. 1.41. D. 1.33. E. 1.15.

Polarization in Reflection and Refraction



In general, light reflected from an interface is partially polarized. **At one particular incidence angle θ_B (the Brewster angle), the reflected light is completely polarized.** For light incident at the Brewster angle, the reflected & refracted rays are ⊥ to each other.



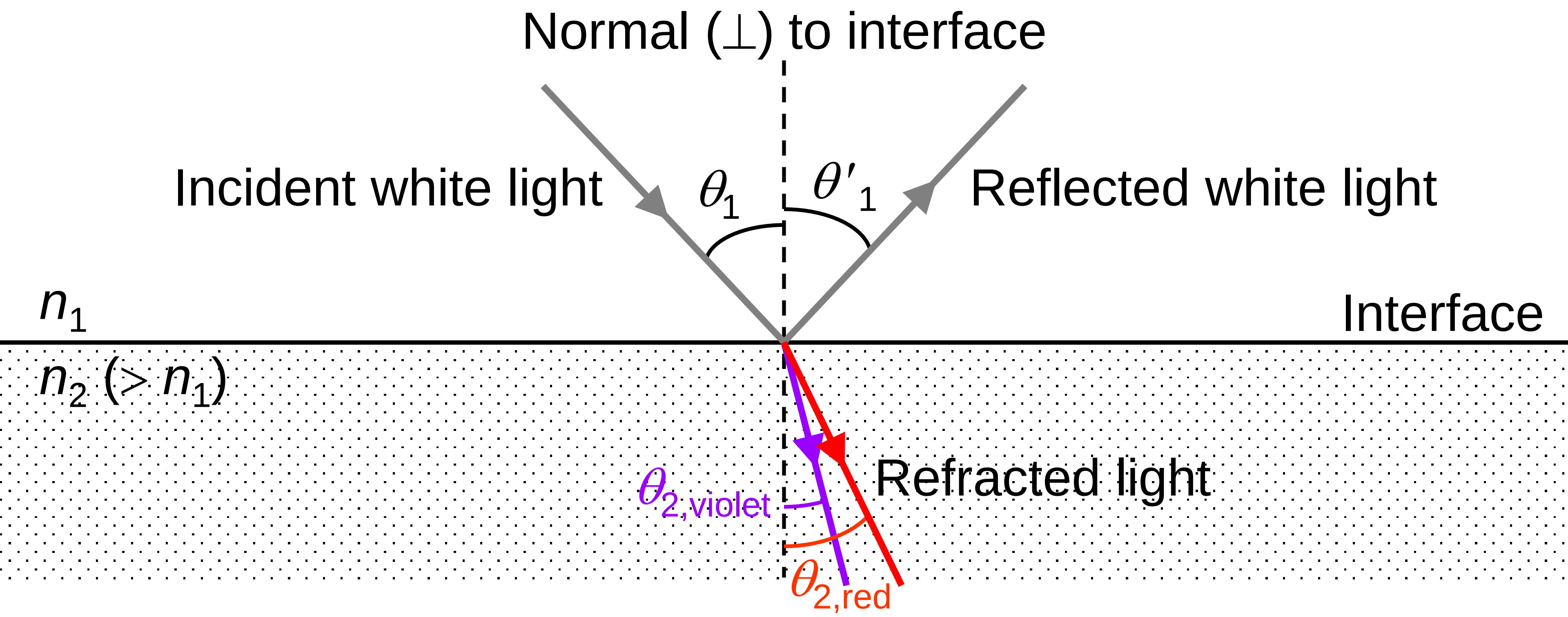
$$\theta_B + \theta_2 = 90°.$$

$$n_1 \sin(\theta_B) = n_2 \sin(\theta_2)$$
$$= n_2 \sin(90° - \theta_B)$$
$$= n_2 \cos(\theta_B).$$

$$\Rightarrow \quad \boxed{\tan(\theta_B) = \frac{n_2}{n_1}.}$$

For Brewster angle θ_B

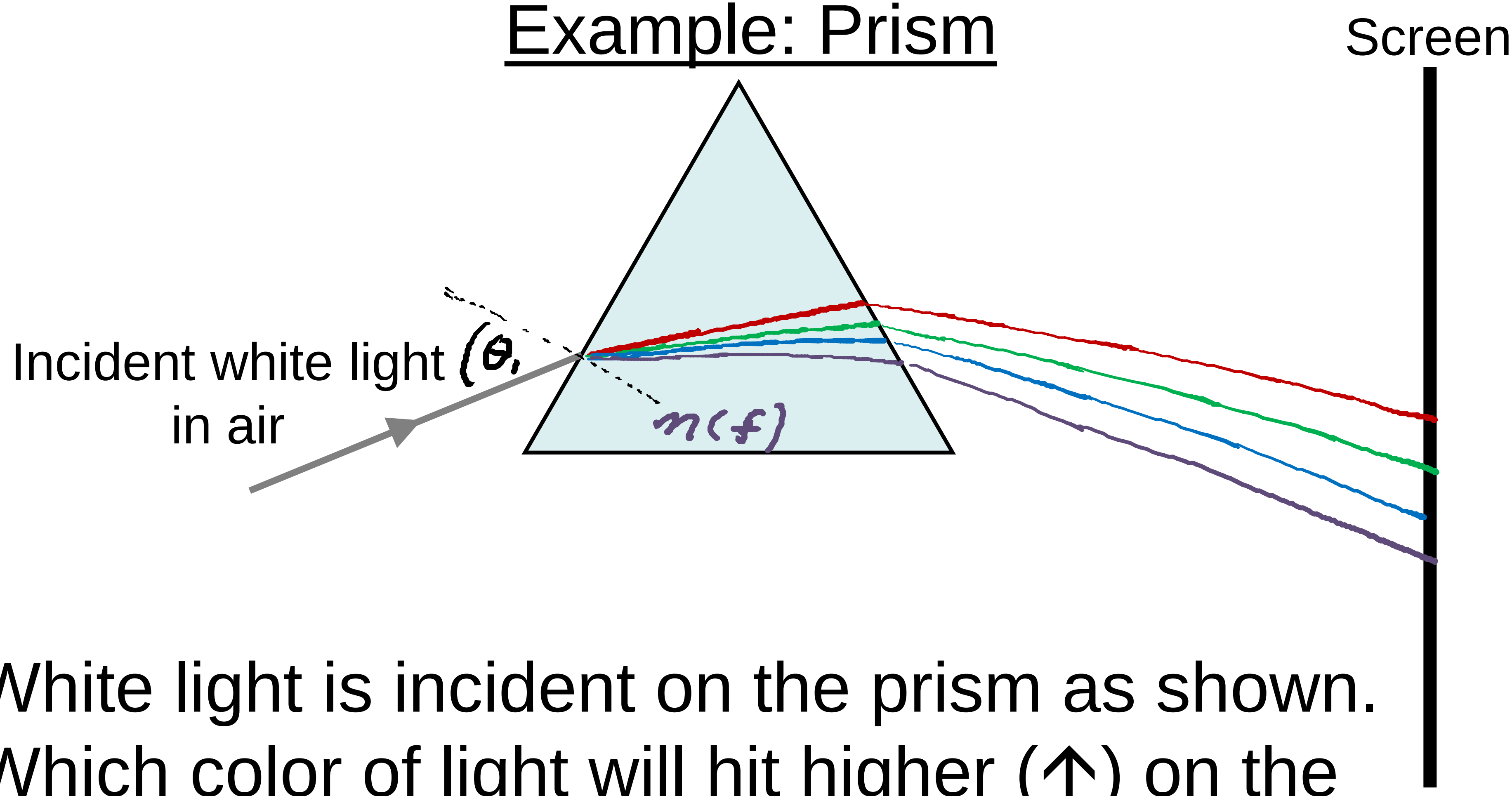
Chromatic dispersion:



Refractive index *n* depends on the wavelength λ (or frequency *f*) of the light. Generally *n* is greater for a shorter wavelength.

-> In general, ***n* (violet) > *n* (red)**

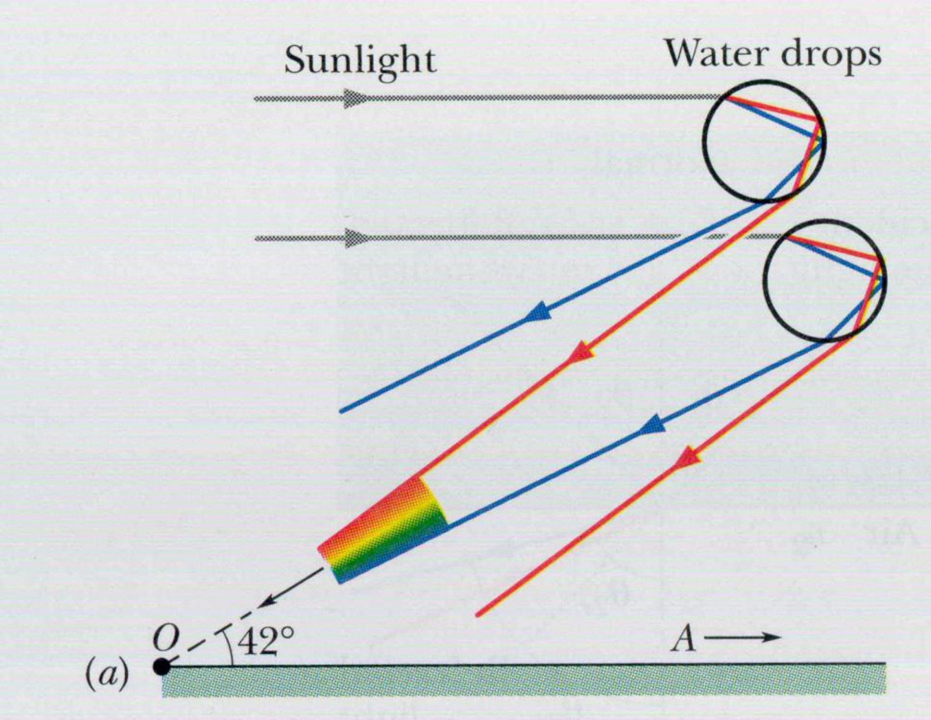
Example: Prism

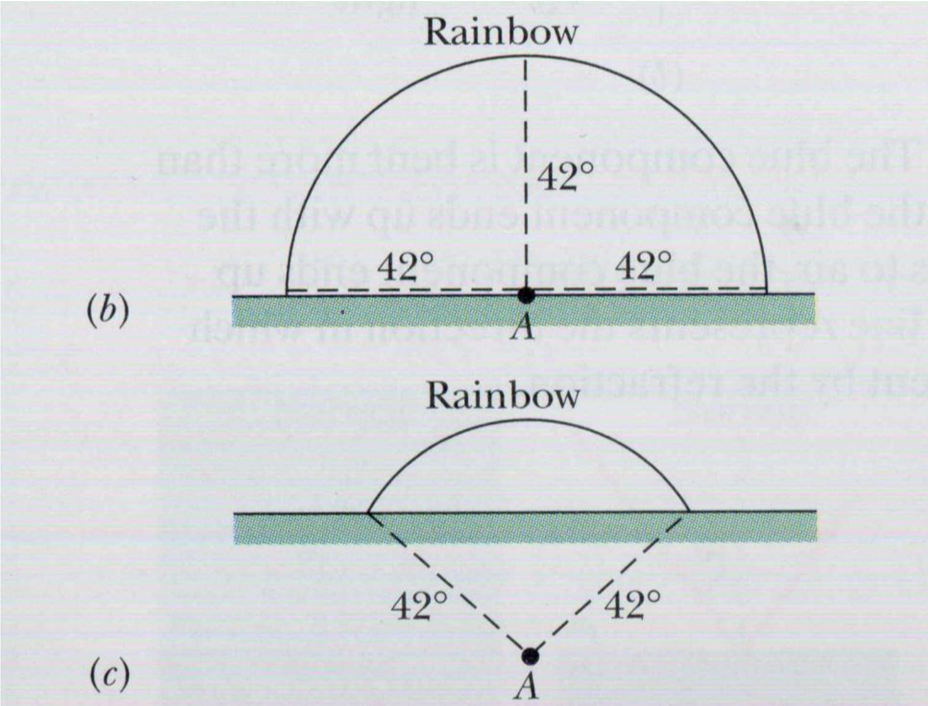


White light is incident on the prism as shown. Which color of light will hit higher (↑) on the screen?

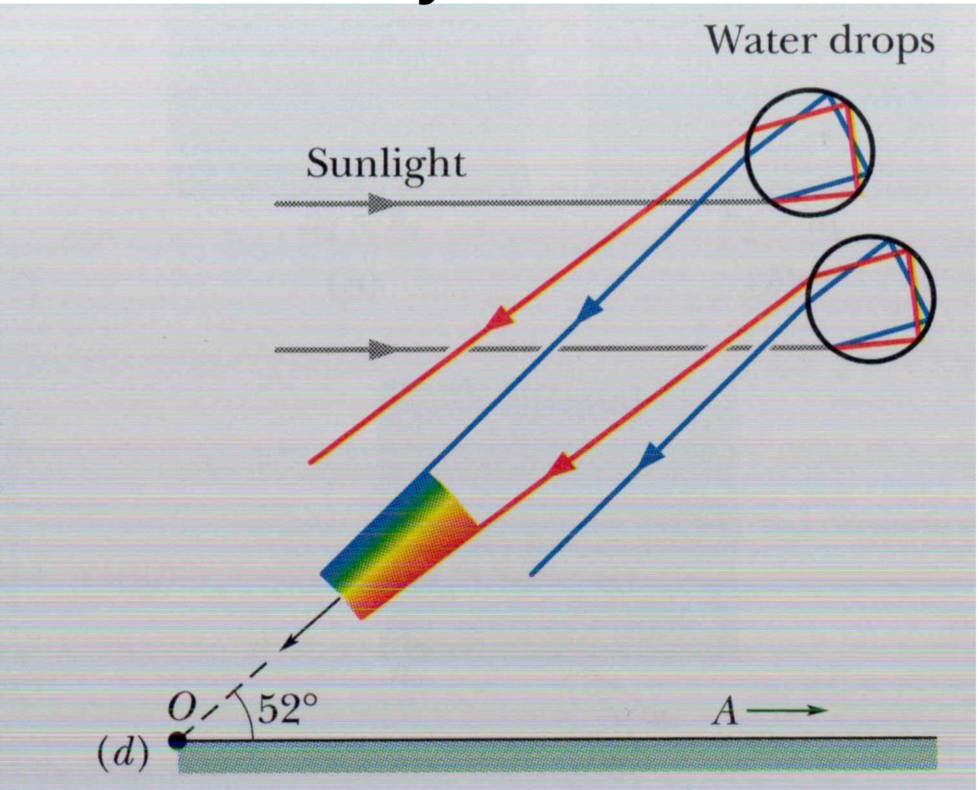
A. Violet B. Blue C. Red

Rainbows:

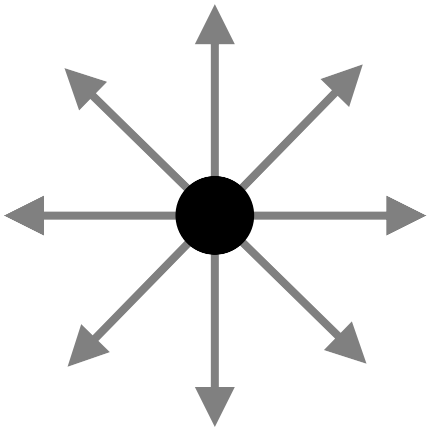




Secondary rainbow:

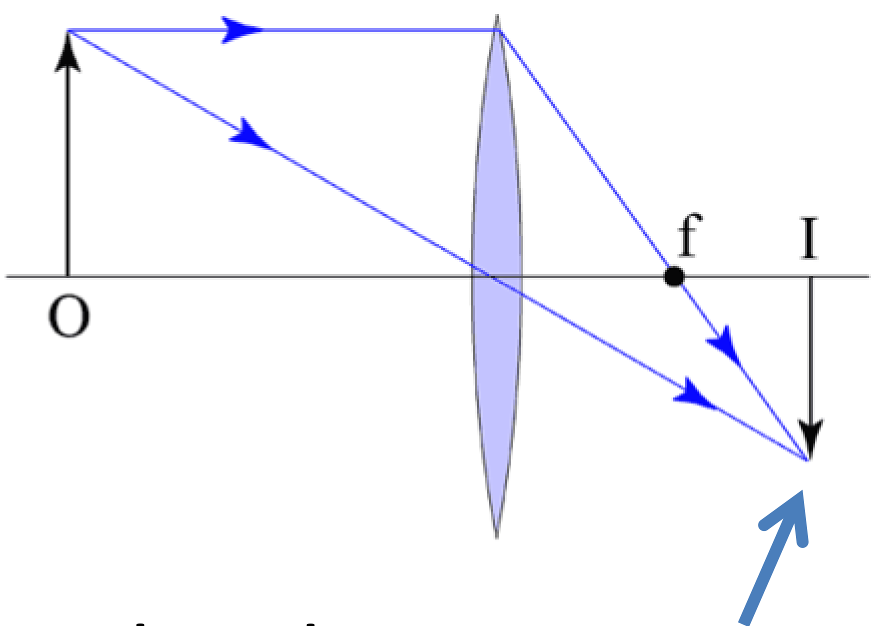


Images:



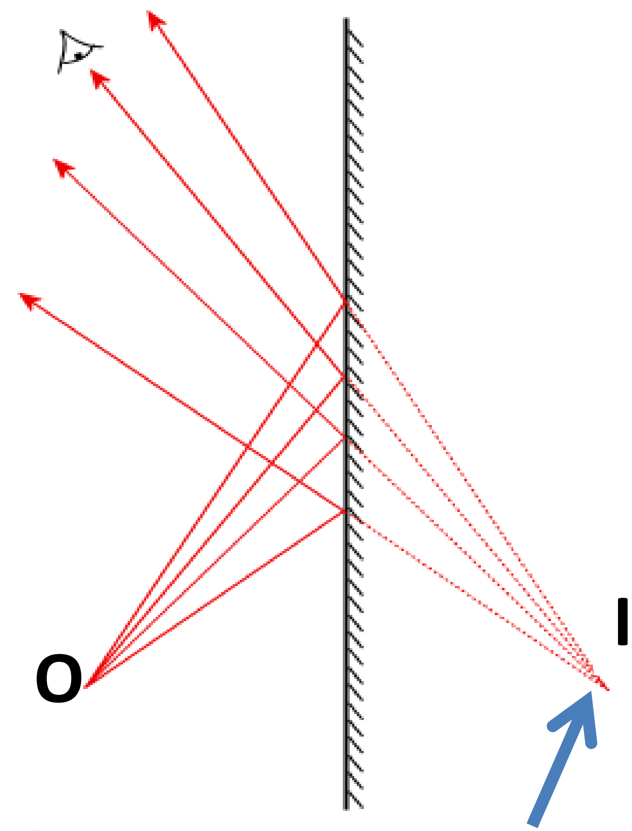
- **Light rays diverge from an object in all directions.**
- **We 'see' the object because some of these rays enter our eyes**
- **We perceive the rays as coming straight from the location of the object / image.**
- **Real images: Perceived location of image is actually a point of convergence of the rays of light that make up the image**
- **Virtual images: Rays only appear to diverge from a point on the image.**

Real image



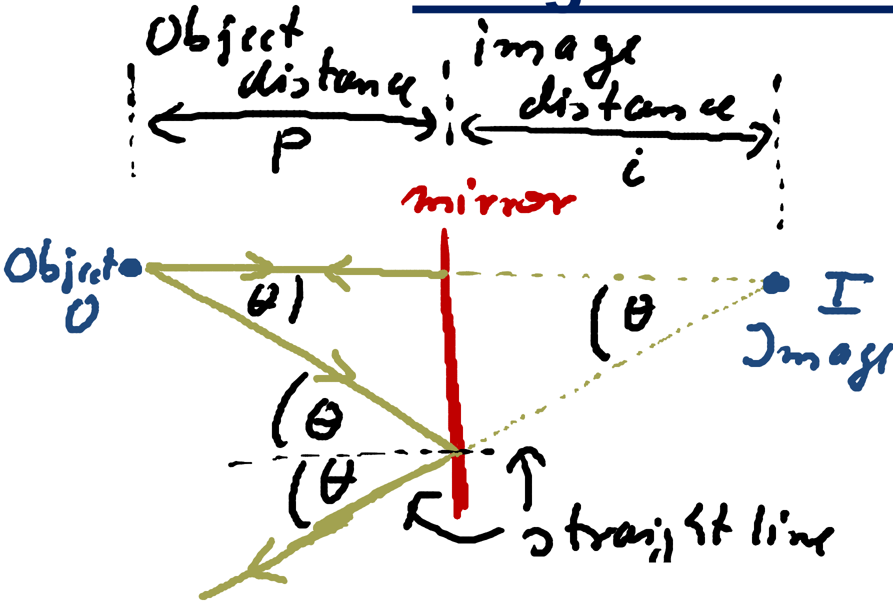
Real rays do converge at location of image (can put a screen at location of image and form the image)

Virtual image



Rays only appear to converge at location of image (your brain thinks the image is at this location, but it is not real)

Image formation by a plane (flat) mirror:

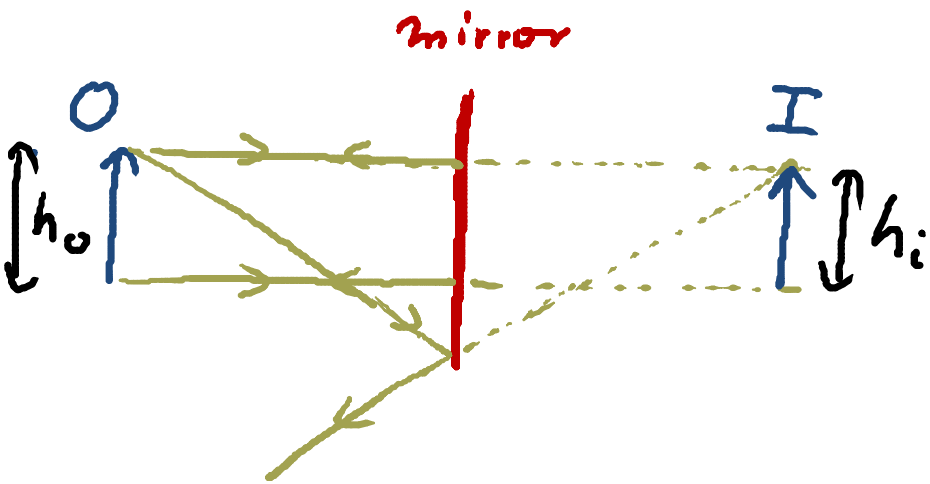


- object distance : $p > 0$
- image distance : $i < 0$ here

Convention: i <0 for virtual images

- for **plane** mirror:

$$i = -p$$



- define:

Lateral Magnification:

$$m = \frac{h_i}{h_o} = \frac{\text{image height}}{\text{object height}}$$

- if $m > 0$: image is upright
- if $m < 0$: image is upside down
- for plane mirror: $m = 1$

A six foot tall man wants to buy a (plane) mirror that will allow him to see all of himself at once.

What must be the (approximate) minimum length of the mirror?

A. 3ft B. 6ft

C. 9ft D. 12 ft

E. **Depends on how far in front of the mirror the man plans to stand.**