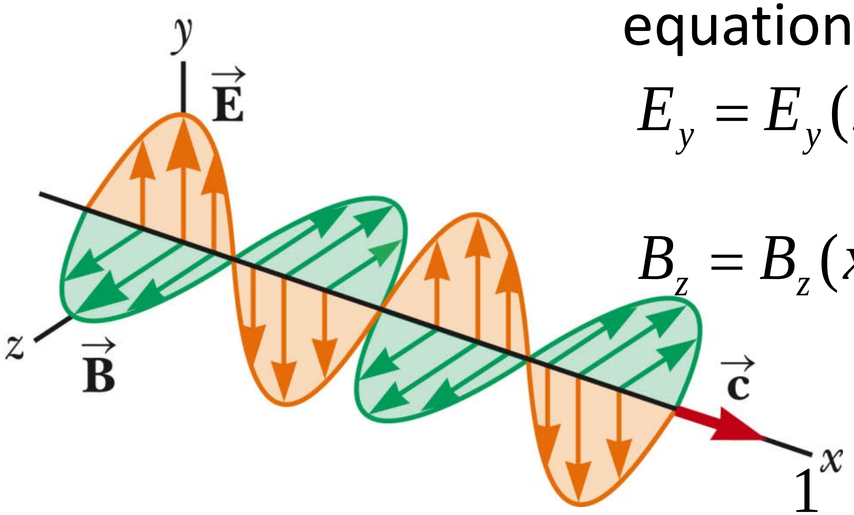
PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 18 (Chapter 35):

Optical properties of light

1. Speed of light in vacuum and in materials
2. Refraction and reflection of light
3. Spectrum of light and dispersion

13	03/08/2012	Faraday's law	31.1-31.5	31.12,31.23,31.40	03/20/2012
	03/13/2012	*No class (Spring Break)*			
	03/15/2012	*No class (Spring Break)*			
14	03/20/2012	Induction and AC circuits	32.1-32.6	32.4,32.20,32.43	03/22/2012
15	03/22/2012	AC circuits	33.1-33.9	33.8,33.24,33.71	03/27/2012
16	03/27/2012	Electromagnetic waves	34.1-34.3	34.3,34.10,34.13	03/29/2012
17	03/29/2012	Electromagnetic waves	34.4-34.7	34.22,34.46,34.57	04/03/2012
18	04/03/2012	Ray optics Evening exam	35.1-35.8	35.20,35.27,35.35	04/10/2012
19	04/05/2012	Image formation Evening exam	36.1-36.4	36.8,36.31,36.42	04/10/2012
20	04/10/2012	Image formation	36.5-36.10	36.52,36.54,36.64	04/12/2012
21	04/12/2012	Wave interference	37.1-37.6		
22	04/17/2012	Diffraction	38.1-38.6		
23	04/19/2012	Quantum Physics	40.1-42.10		



Plane wave solution to Maxwell's equations in vacuum:

$$E_y = E_y(x,t) = E_{\max}\cos(k(x-ct))$$

$$B_z = B_z(x,t) = \frac{E_{\max}}{c}\cos(k(x-ct))$$

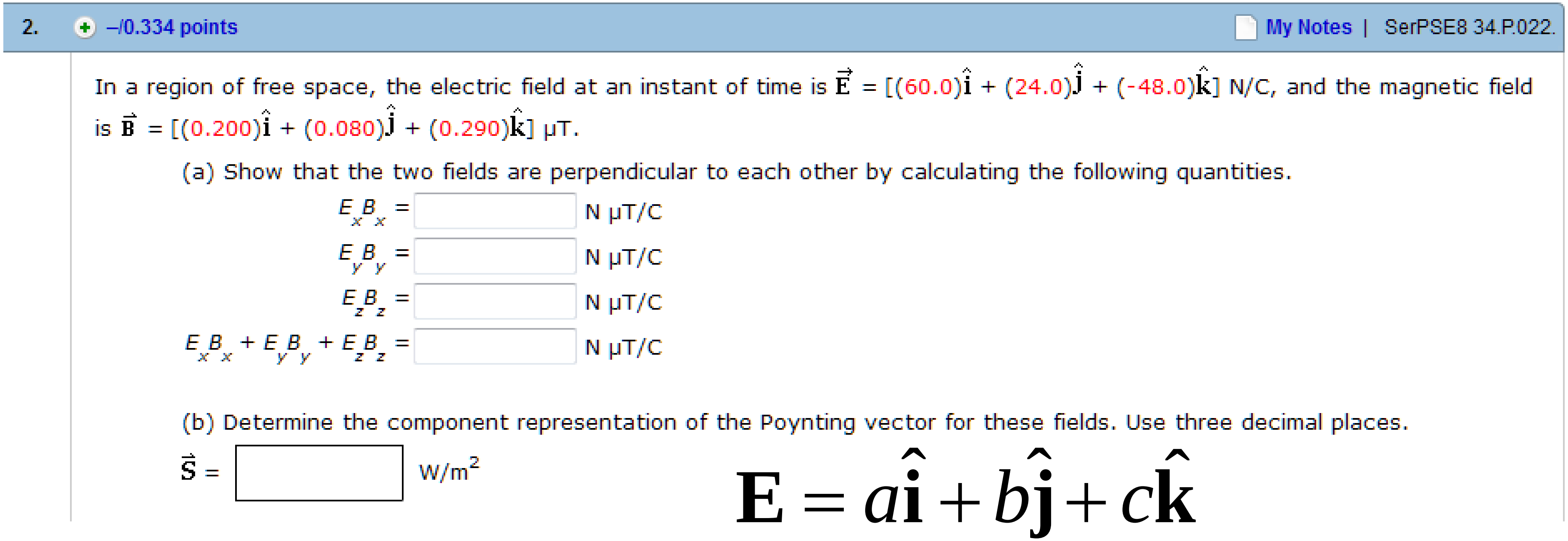
$$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = 2.99792458\times10^8 m/s \approx 3\times10^8 m/s$$

Additional comments:

For this solution, the **y** direction is called the **polarization** direction (the E field orientation)

This is a periodic wave, where $k=2\pi/\lambda$ and λ represents the wavelength and the frequency of the wave is $kc=\omega=2\pi f$.

Webassign hint:



In a region of free space, the electric field at an instant of time is $\vec{E} = [(60.0)\hat{i} + (24.0)\hat{j} + (-48.0)\hat{k}]$ N/C, and the magnetic field is $\vec{B} = [(0.200)\hat{i} + (0.080)\hat{j} + (0.290)\hat{k}]$ μT.

(a) Show that the two fields are perpendicular to each other by calculating the following quantities.

$E_xB_x =$ ☐ N μT/C

$E_yB_y =$ ☐ N μT/C

$E_zB_z =$ ☐ N μT/C

$E_xB_x + E_yB_y + E_zB_z =$ ☐ N μT/C

(b) Determine the component representation of the Poynting vector for these fields. Use three decimal places.

$\vec{S} =$ ☐ W/m^2

$$\mathbf{E} = a\hat{\mathbf{i}} + b\hat{\mathbf{j}} + c\hat{\mathbf{k}}$$

$$\mathbf{B} = d\hat{\mathbf{i}} + e\hat{\mathbf{j}} + f\hat{\mathbf{k}}$$

$$\mathbf{S} = \frac{1}{\mu_0}\mathbf{E}\times\mathbf{B}$$

$$\hat{\mathbf{i}}\times\hat{\mathbf{j}} = \hat{\mathbf{k}} = -\hat{\mathbf{j}}\times\hat{\mathbf{i}}$$

$$\hat{\mathbf{j}}\times\hat{\mathbf{k}} = \hat{\mathbf{i}} \quad \hat{\mathbf{k}}\times\hat{\mathbf{i}} = \hat{\mathbf{j}}$$

Index of refraction n:

In vacuum:

$$\varepsilon_0$$

$$\mu_0$$

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

In medium:

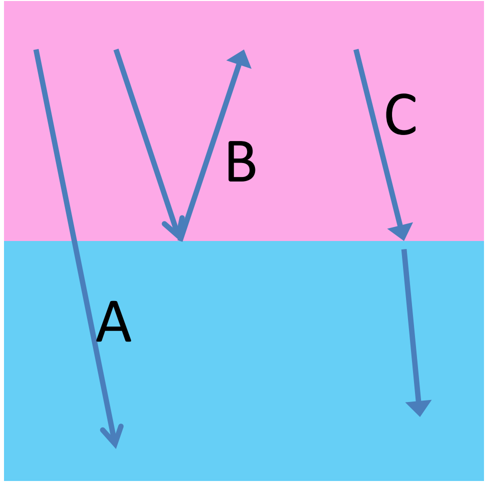
$$\varepsilon \geq \varepsilon_0$$

$$\mu \geq \mu_0$$

$$v = \frac{1}{\sqrt{\varepsilon\mu}} \equiv \frac{c}{n}$$

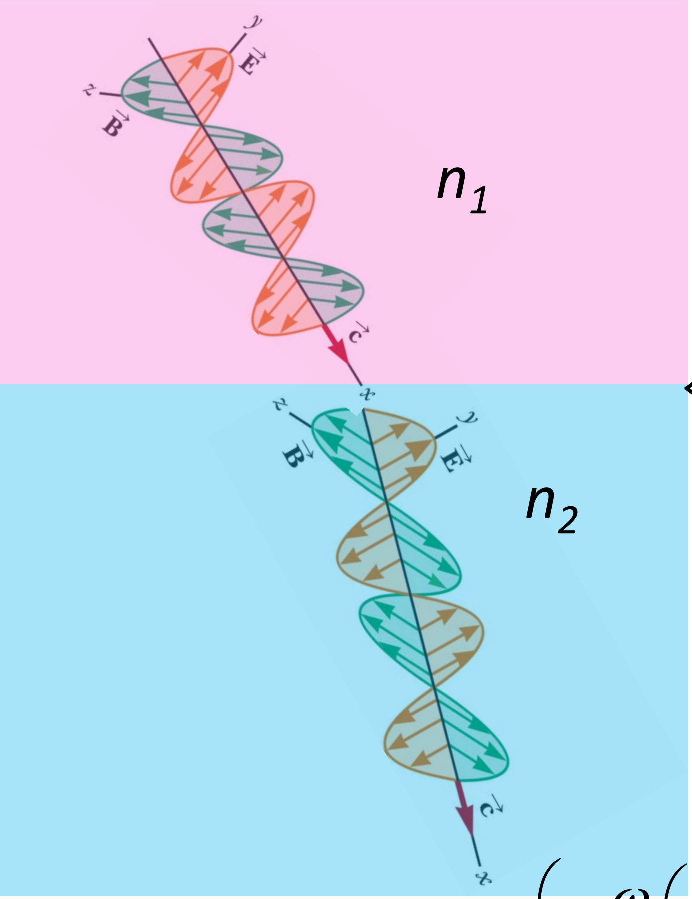
What happens to an electromagnetic wave traveling when it encounters a different medium?

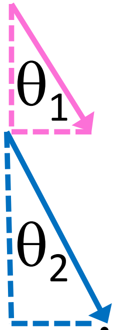
A. It usually passes through the medium without any change
B. It usually passes through the medium but the velocity is changed
C. It usually passes through the medium with a different velocity; the E and B fields are also changed
D. It usually cannot pass through the different medium



What happens to the propagation of an electromagnetic wave traveling when it encounters a different medium?

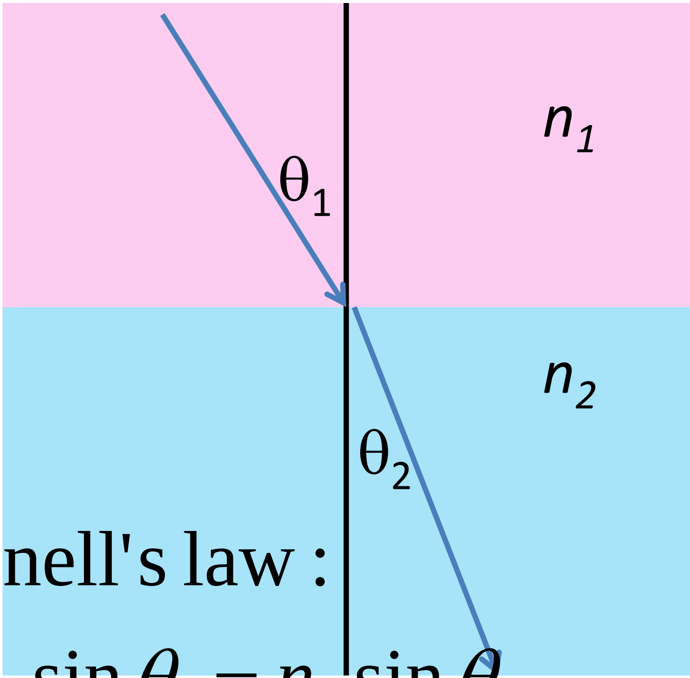
A. The propagation vector continues the medium without change
B. The propagation vector is reflected before passing second medium
C. The propagation vector changes when it passes through the medium
D. More than one possibility





$$n_1 \frac{\omega}{c} \sin\theta_1 = n_2 \frac{\omega}{c} \sin\theta_2$$

$\Leftarrow$ **E** and **B** continuous at boundary



$$E_y = E_y(x,t) = E_{\max} \cos\left(n\frac{\omega}{c}\left(x - \frac{c}{n}t \right)\right)$$

$$B_z = B_z(x,t) = \left(E_{\max} n / c \right) \cos\left(n\frac{\omega}{c}\left(x - \frac{c}{n}t \right)\right)$$

Snell's law :

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

Indices of refraction for various media:

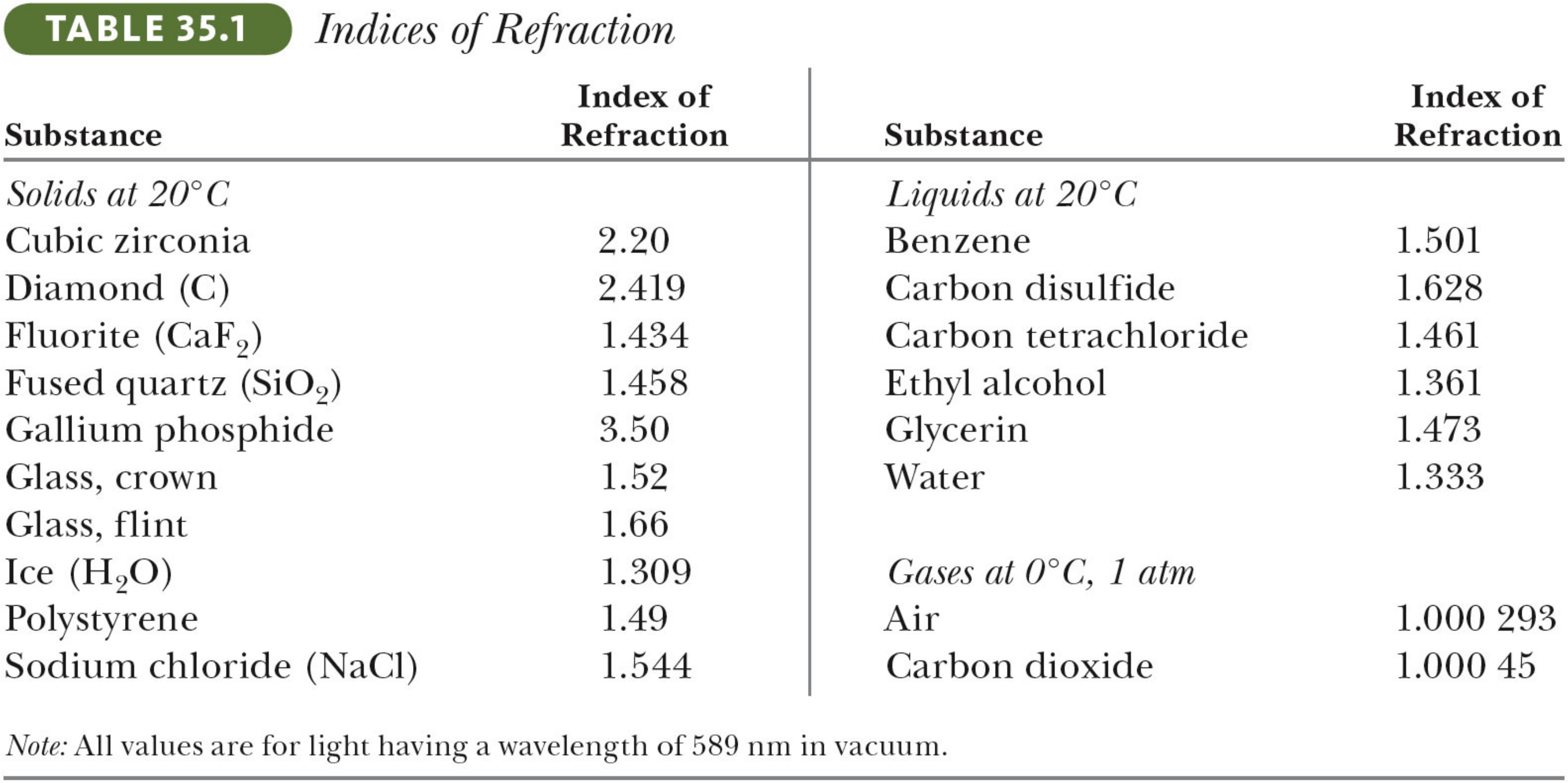


TABLE 35.1 *Indices of Refraction*

Substance	**Index of Refraction**	**Substance**	**Index of Refraction**
Solids at 20°C		*Liquids at 20°C*	
Cubic zirconia	2.20	Benzene	1.501
Diamond (C)	2.419	Carbon disulfide	1.628
Fluorite (CaF_2)	1.434	Carbon tetrachloride	1.461
Fused quartz (SiO_2)	1.458	Ethyl alcohol	1.361
Gallium phosphide	3.50	Glycerin	1.473
Glass, crown	1.52	Water	1.333
Glass, flint	1.66		
Ice (H_2O)	1.309	*Gases at 0°C, 1 atm*	
Polystyrene	1.49	Air	1.000 293
Sodium chloride (NaCl)	1.544	Carbon dioxide	1.000 45

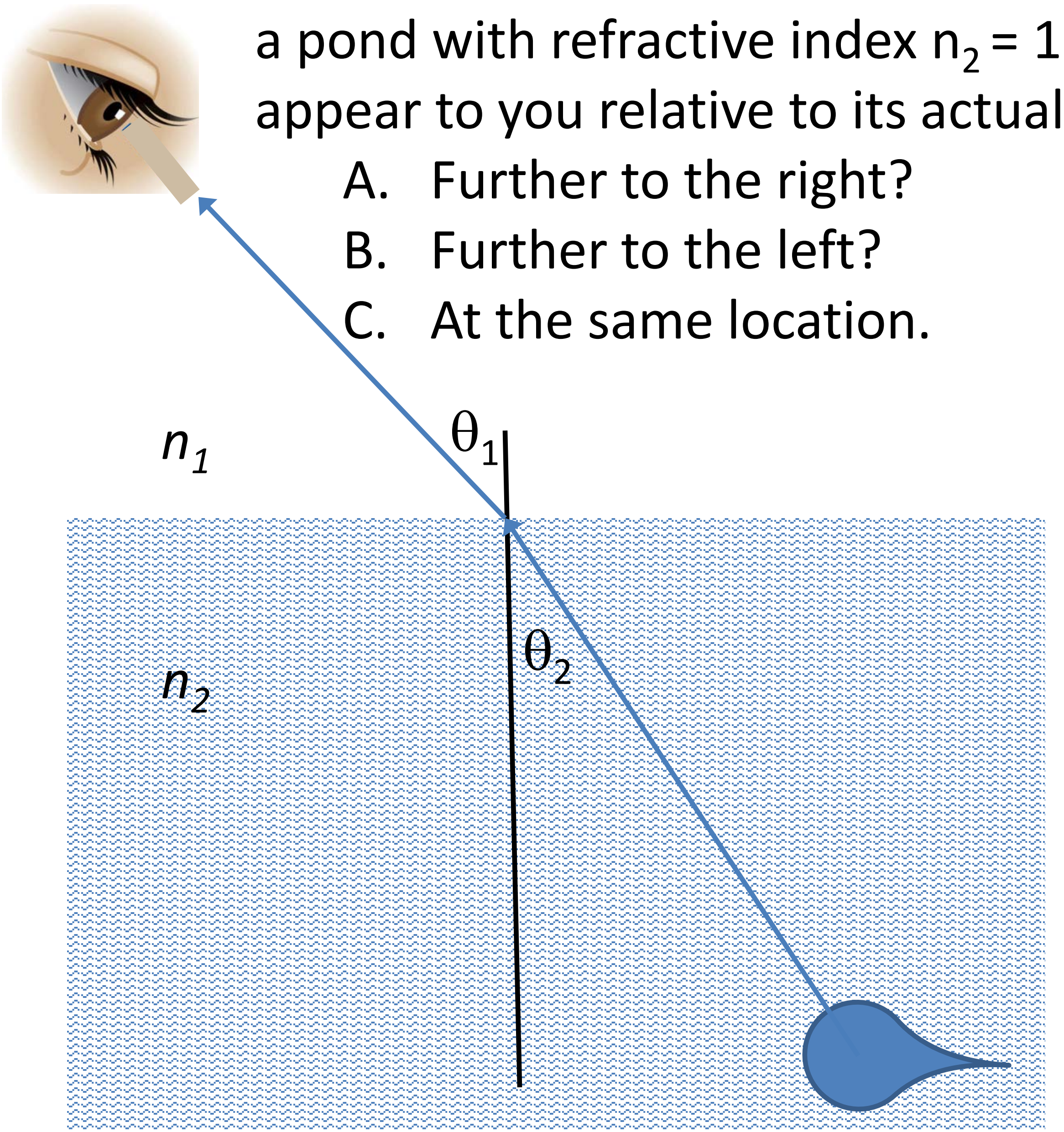
Note: All values are for light having a wavelength of 589 nm in vacuum.

Suppose that you observe , at an angle of $\theta_1 = 45^o$, a fish in a pond with refractive index $n_2 = 1.333$. How does the fish appear to you relative to its actual location

A. Further to the right?

B. Further to the left?

C. At the same location.



Suppose that you observe , at an angle of $\theta_1 = 45^o$, a fish in a pond with refractive index $n_2 = 1.333$. How does the fish appear to you relative to its actual location

A. Further to the right?

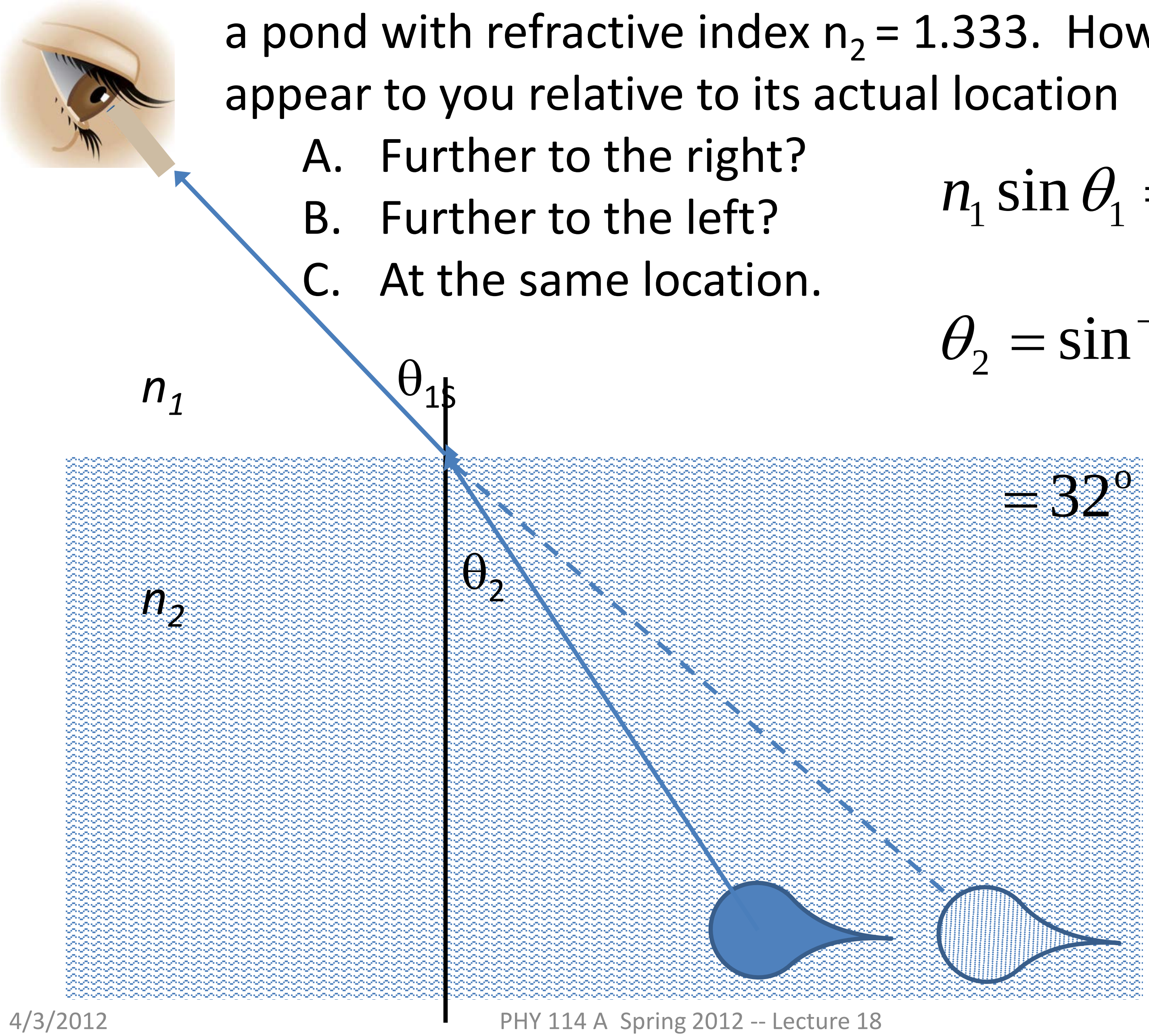
B. Further to the left?

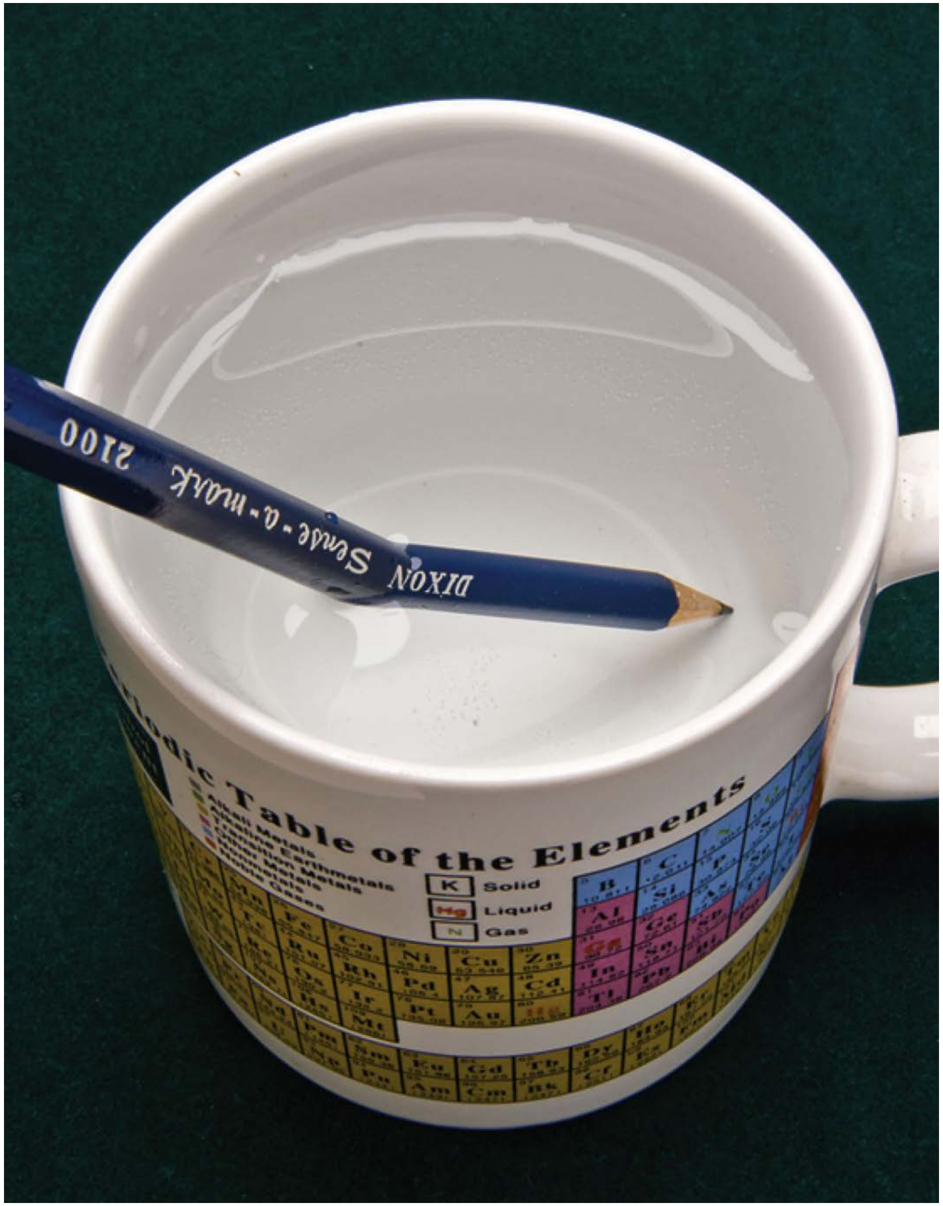
C. At the same location.

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

$$\theta_2 = \sin^{-1}\left(\frac{\sin 45^o}{1.333}\right)$$

$$= 32^o$$

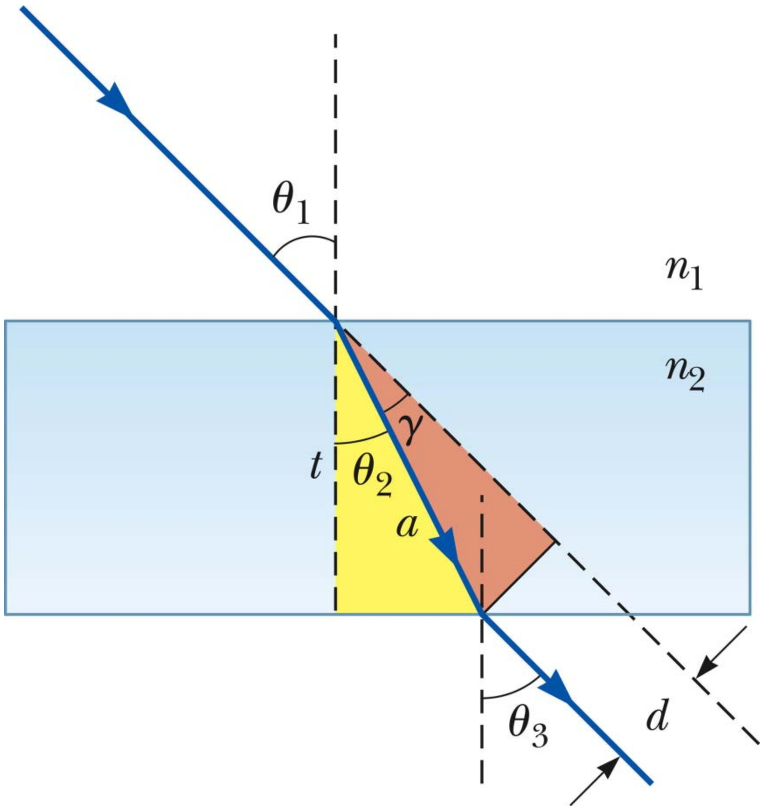




The picture to the left

A. Is consistent with Snell's law
B. Shows that Snell's law is false
C. Shows that water bends pencils

Light through a slab



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

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

$$\gamma = \theta_1 - \theta_2$$

$$d = a \sin\gamma$$

$$a = \frac{t}{\cos\theta_2}$$

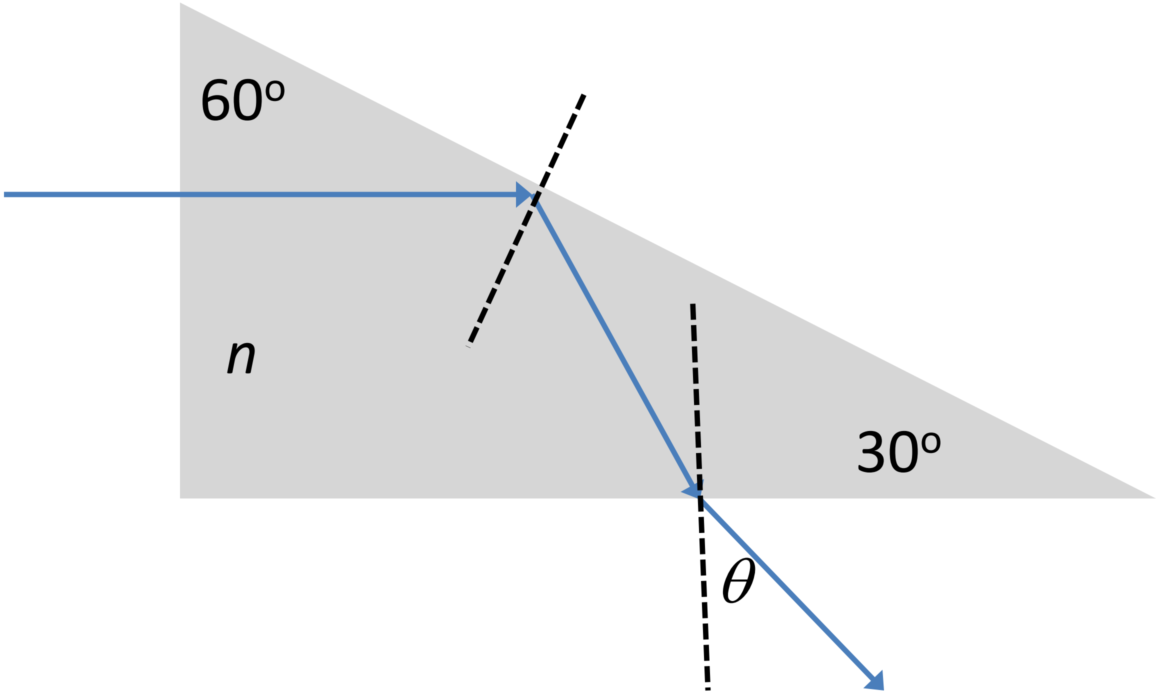
What is the value of θ_3?

A. θ_1

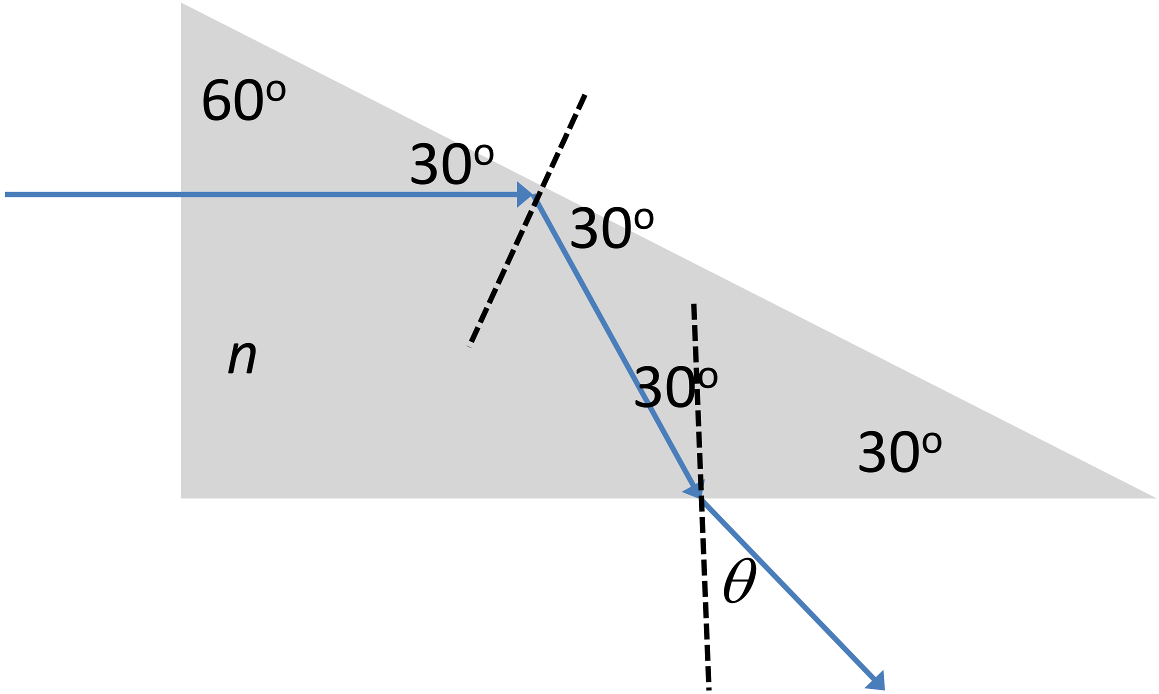
B. θ_2

C. $\theta_1 + \theta_2$

More geometrical optics



More geometrical optics



$$n \sin 30^o = \sin \theta$$

$$\text{For } n = 1.333$$

$$\theta = 41.8^o$$

Which of the following statements is true:

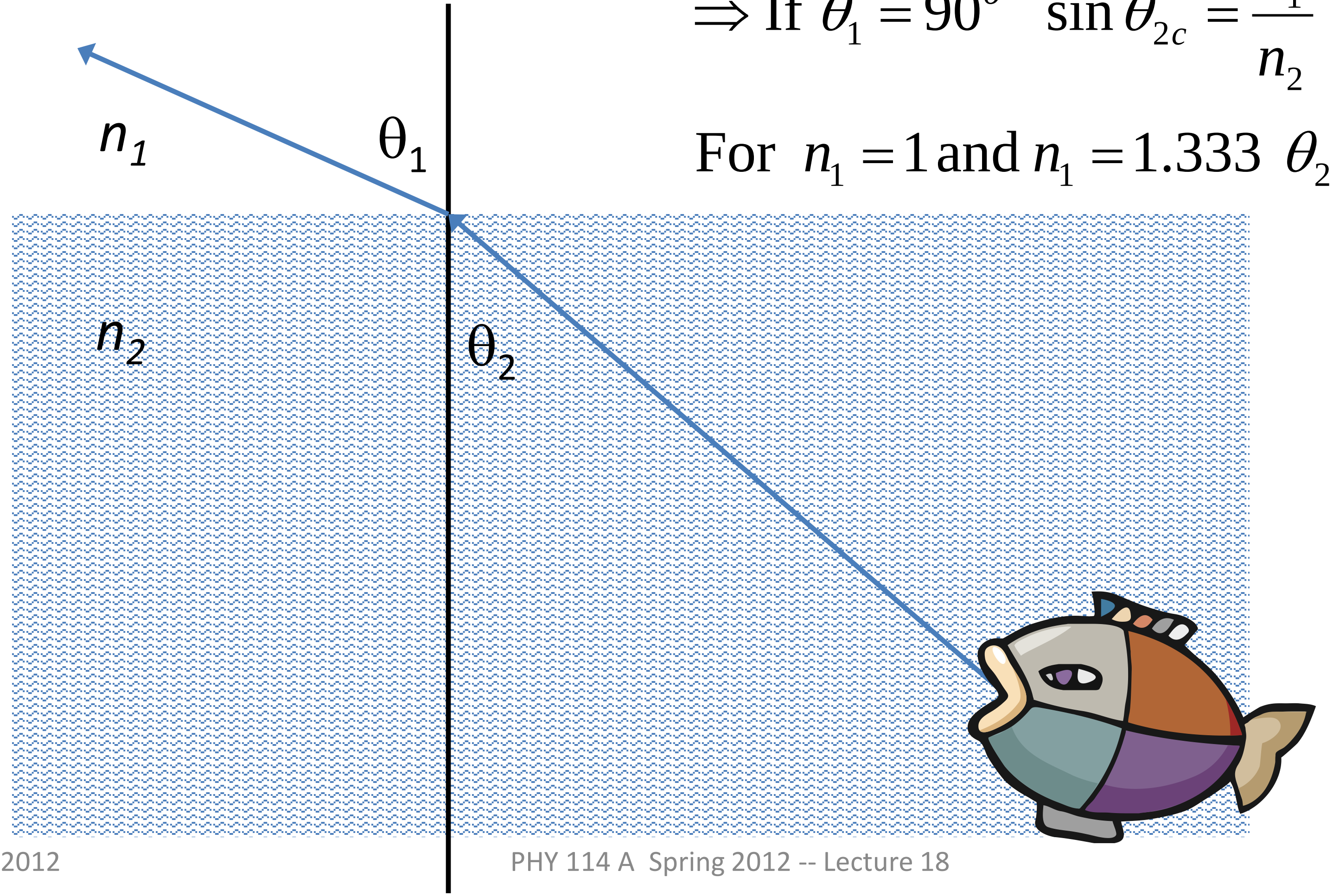
A. $0 < \theta_2 < 90^o$
B. $0 < \theta_2 < \theta_c$
C. $\theta_2 > \theta_1$

$$0 \le \theta_1 \le 90^o$$

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

$$\Rightarrow \text{If } \theta_1 = 90^o \quad \sin\theta_{2c} = \frac{n_1}{n_2}$$

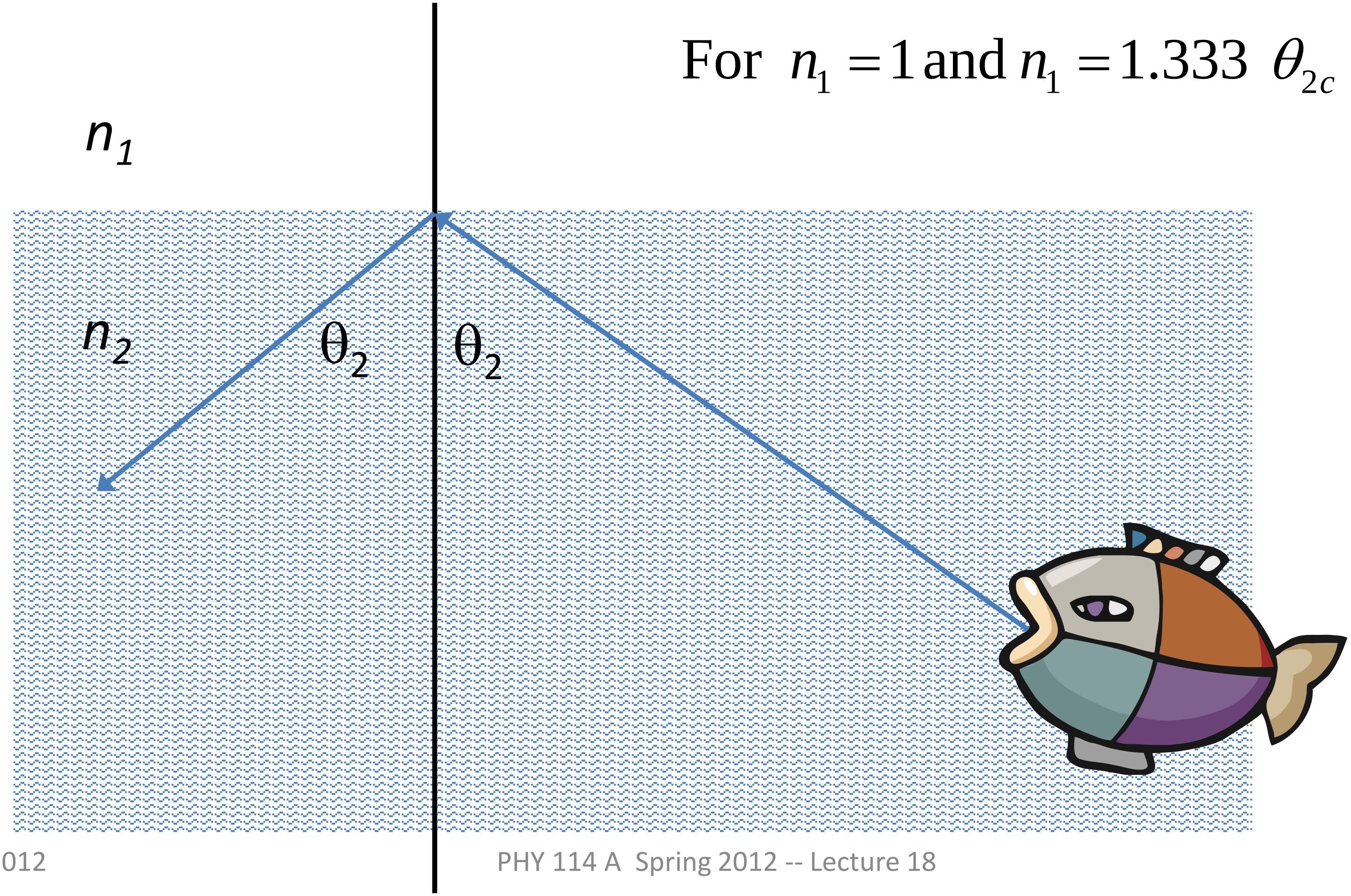
$$\text{For } n_1 = 1 \text{ and } n_1 = 1.333 \;\; \theta_{2c} = 48.6^o$$



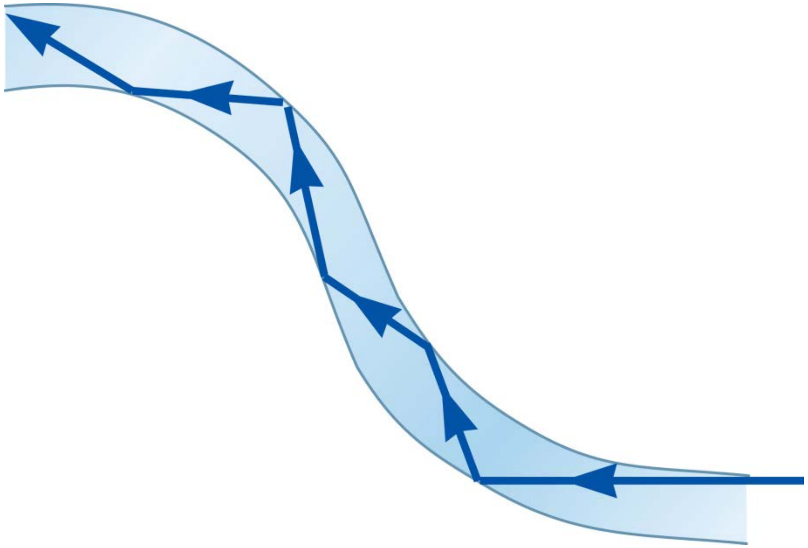
Total internal reflection for $\theta_2 > \theta_c$

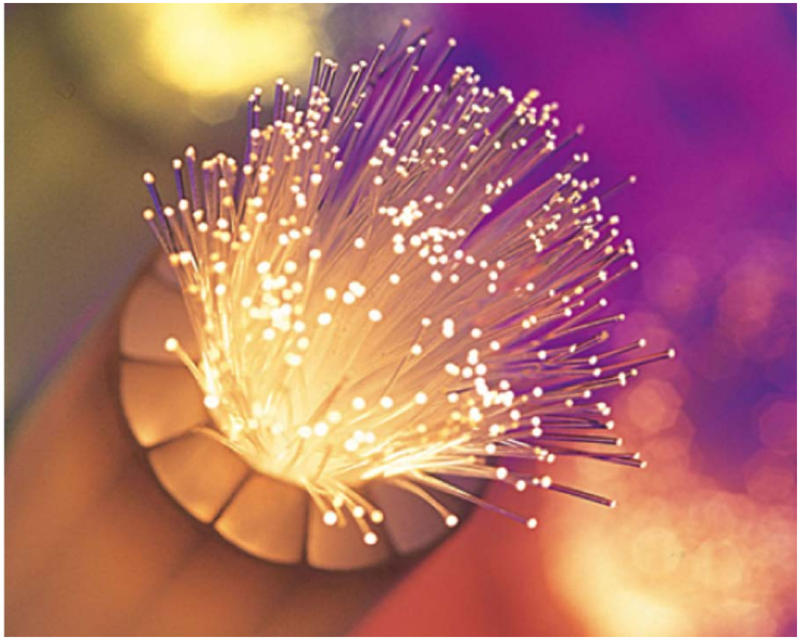
$$\sin\theta_{2c} = \frac{n_1}{n_2}$$

For $n_1 = 1$ and $n_1 = 1.333$ $\theta_{2c} = 48.6^o$

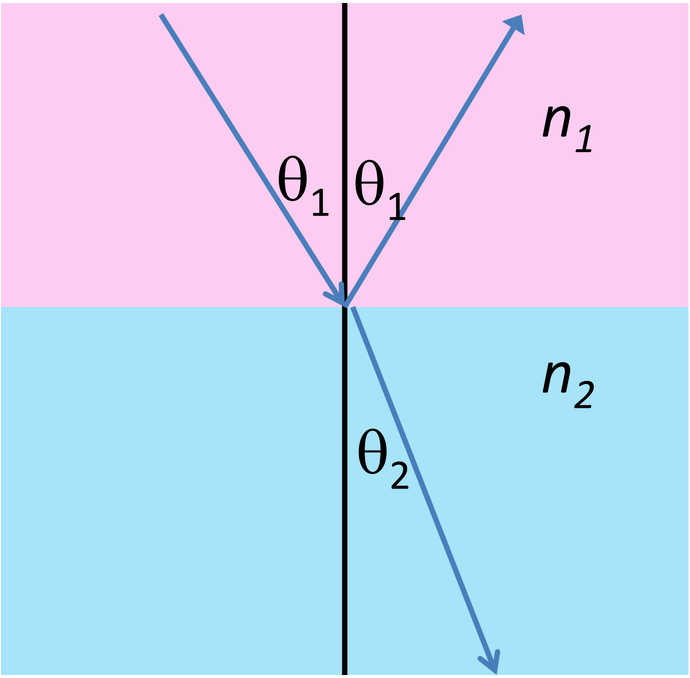


Uses for total internal reflection – fiber optic cables





General case – reflection and refraction



For E polarized in scattering plane

$$\frac{E_2}{E_0} = \frac{2n_1 n_2 \cos\theta_1}{n_2^2 \cos\theta_1 + n_1 n_2 \cos\theta_2}$$

$$\frac{E_{1R}}{E_0} = \frac{n_2^2 \cos\theta_1 - n_1 n_2 \cos\theta_2}{n_2^2 \cos\theta_1 + n_1 n_2 \cos\theta_2}$$

For E polarized out of scattering plane

$$\frac{E_2}{E_0} = \frac{2n_1 \cos\theta_1}{n_1 \cos\theta_1 + n_2 \cos\theta_2}$$

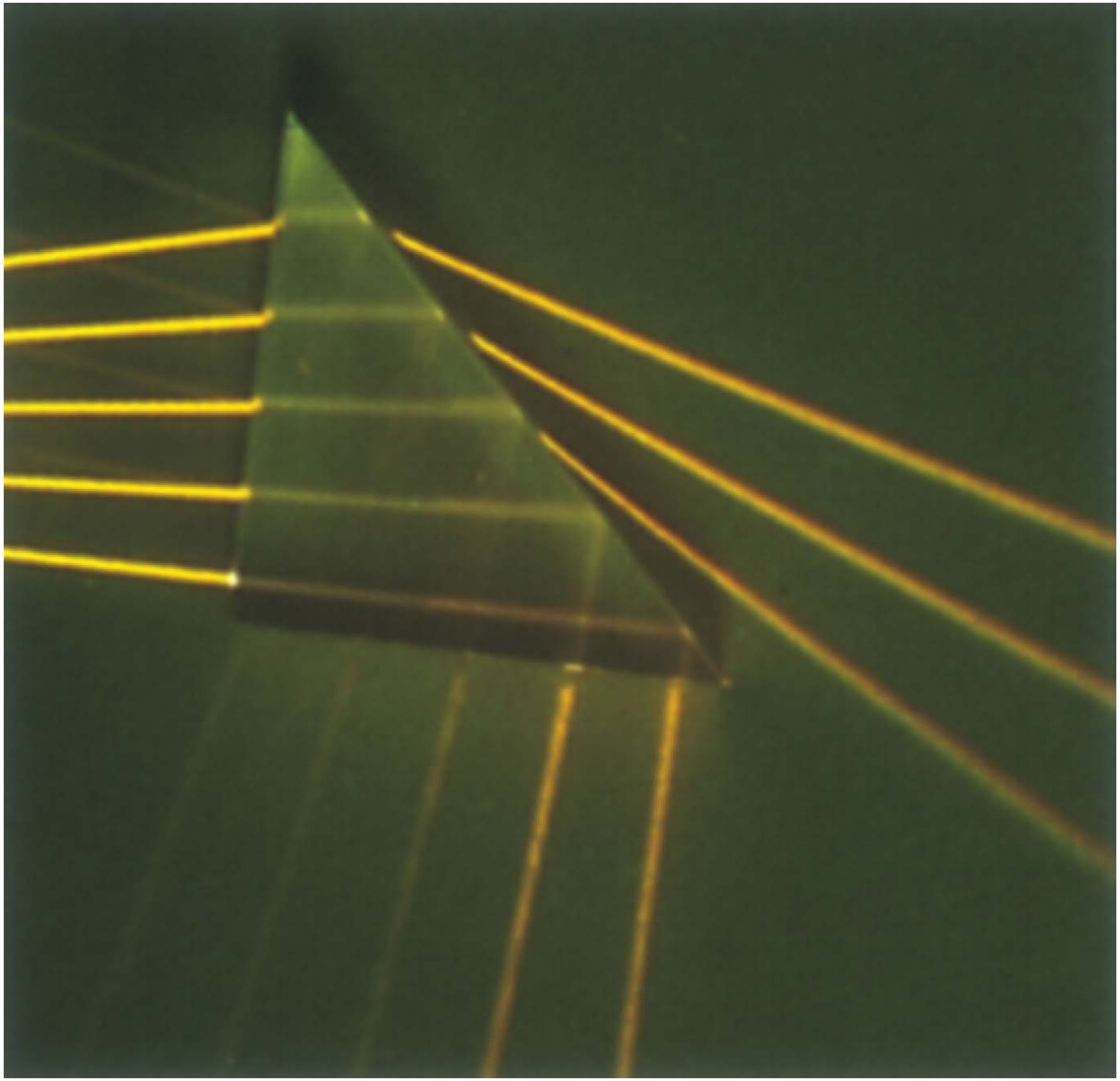
$$\frac{E_{1R}}{E_0} = \frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2}$$

For $\theta_1 = 0 = \theta_2$

$$\frac{E_2}{E_0} = \frac{2n_1}{n_2 + n_1}$$

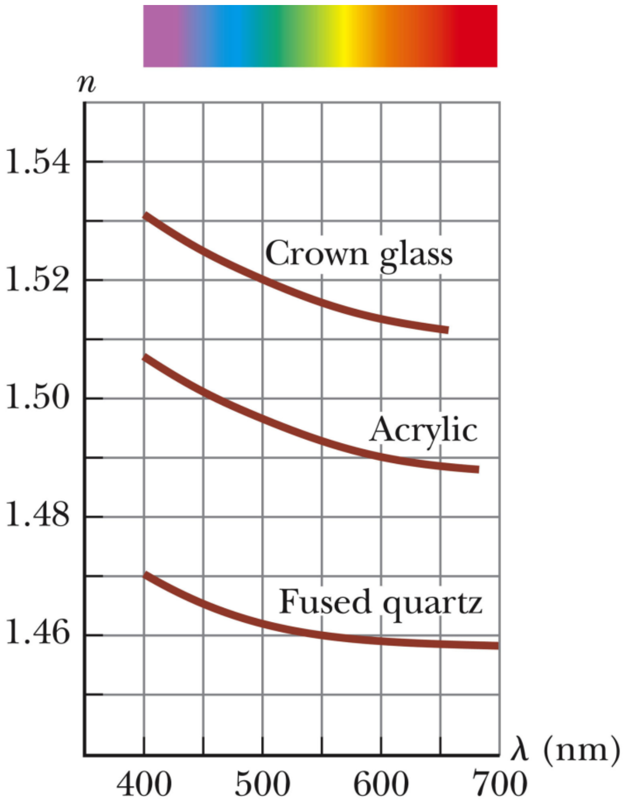
$$\frac{E_{1R}}{E_0} = \frac{n_2 - n_1}{n_2 + n_1}$$

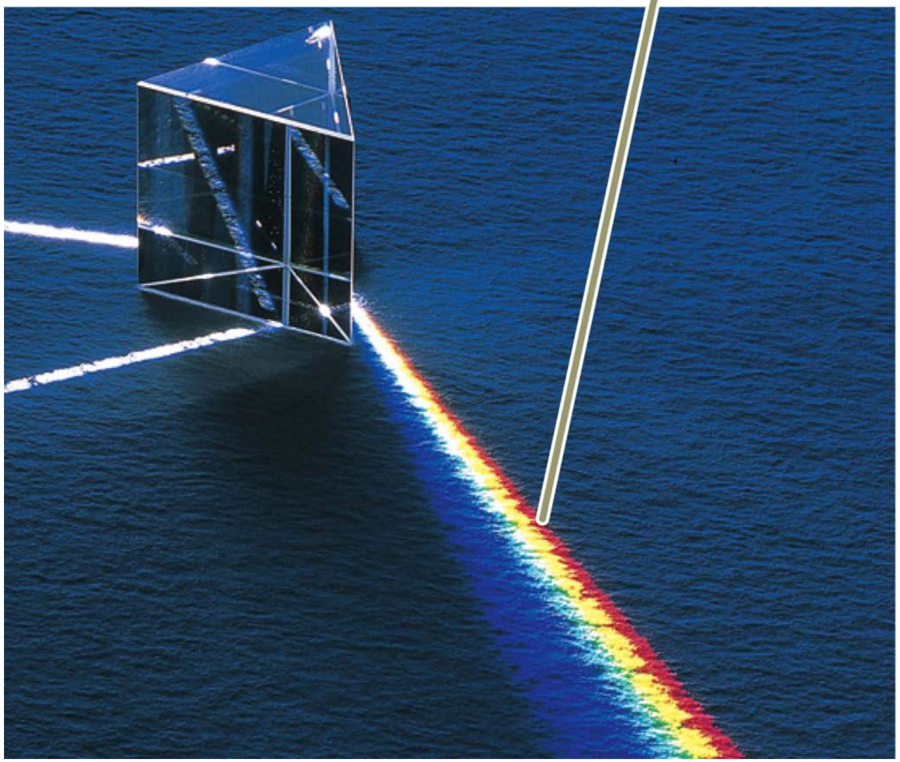
General case – reflection and refraction and multiple surfaces



Dispersion

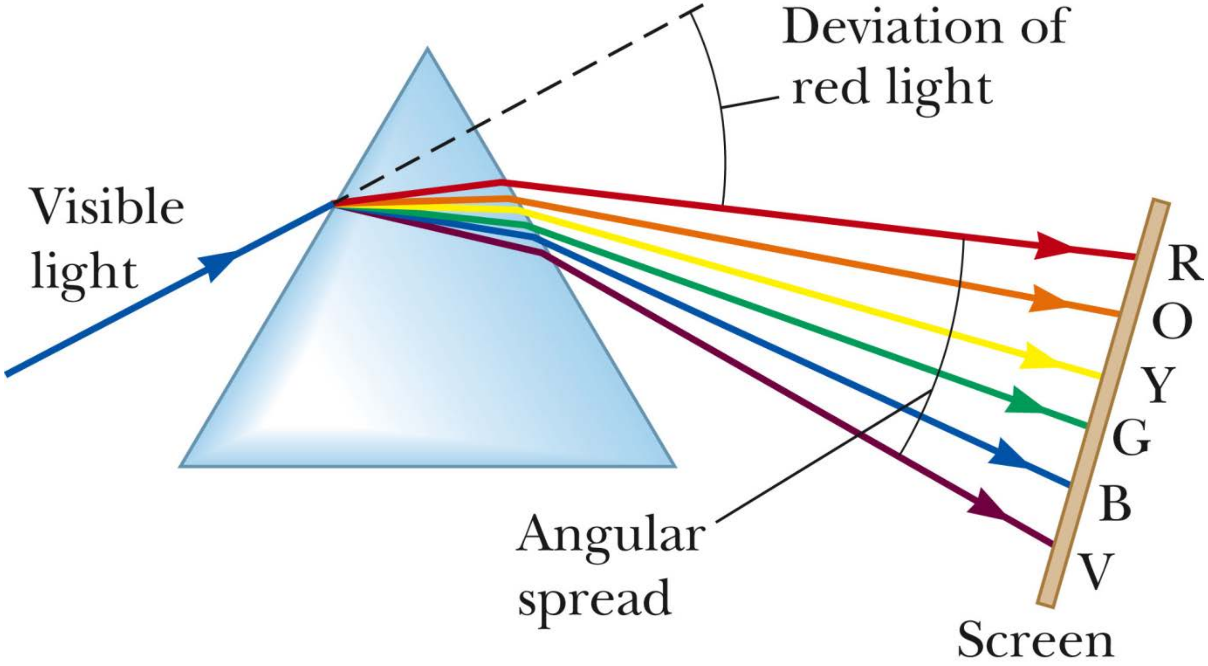
$n=n(\lambda)$





The colors in the refracted beam are separated because dispersion in the prism causes different wavelengths of light to be refracted through different angles.

Dispersion from prism



Where is the pot of gold?

A. Primary rainbow
B. Secondary rainbow
C. Both

Imagine you are viewing this scene. Where is the sun?

A. To your right
B. To your left
C. Behind you
D. In front of you