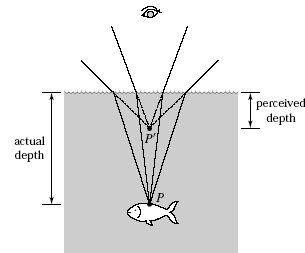


PHY 114 – Summer 2009 - Midterm 3 Solutions

Conceptual Question 1:

A fish swims below the surface of the water. Suppose an observer is looking at the fish from point O' — straight above the fish. Where would the observer see the fish?

Light rays from the fish will go to your right and left eyes. These rays will appear to diverge from a point P' in the water that is closer to the surface than the fish.



Conceptual Question 2:

The lens on the right is made out of a transparent plastic with index of refraction of 1.2.

- (a) When the lens is surrounded by air, is it converging or diverging? Explain.
- (b) Suppose we submerge the lens in water ($n = 1.3$). Is the lens converging or diverging? Explain.



- (a) Since the front surface of the lens is convex ($r > 0$) and the back surface concave ($r < 0$), the focal length will be positive and the lens will be converging.
- (b) Since the surrounding medium will have a higher index than the lens, the focal length will be negative and the lens diverging.

Problem 1:

One of the advantages of laser light compared to light from a regular light source such as an incandescent light bulb is that it is directional (it does not spread).

- (a) Compare the intensity of light from a 3mW laser pointer with a beam diameter of 2 mm to the intensity of light from a 100W light bulb at a distance of 10 meters. Assume that the light bulb operates at an efficiency of 10 % and that the diameter of a laser beam remains constant.
- (b) What is the maximum value of the electric field of the laser beam?

- (a) Since the diameter of the laser beam stays constant,

$$I_{laser} = \frac{P_{laser}}{A_{laser}} = \frac{P_{laser}}{\pi(d_{laser}/2)^2} = \frac{3mW}{\pi(2mm/2)^2} = 955W/m^2$$

On the other hand, the light from the bulb expand in all directions.

$$I_{bulb} = \frac{P_{bulb}}{A_{bulb}} = \frac{(Eff)P_{bulb,elec}}{4\pi r_{bulb}^2} = \frac{(0.1)(100W)}{4\pi(10m)^2} = 7.96mW/m^2$$

The intensity of the laser pointer is about 120,000 times stronger than the light bulb.

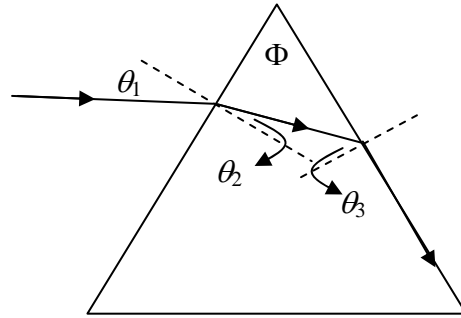
$$(b) I = \frac{E_{\max} B_{\max}}{2\mu_0} = \frac{E_{\max} E_{\max}}{2\mu_0 c}$$

$$\text{Then, } E_{\max} = \sqrt{2\mu_0 c I} = \sqrt{2(4\pi \times 10^{-7})(3 \times 10^8)(955)} = 848.6 \text{ V/m}$$

Problem 2:

An equilateral triangular prism with an apex angle of $\Phi = 60.0^\circ$ has an index of refraction $n = 1.50$. What is the smallest angle of incidence θ_1 for which a light ray can emerge from the other side?

Bonus: If $\theta_1 = 20^\circ$, trace the path of the beam until it exits the prism. Determine all the relevant angles.



The limiting angle is when θ_3 is equal to the critical angle.

$$\theta_3 = \theta_c = \arcsin\left(\frac{1}{n}\right) = \arcsin\left(\frac{1}{1.50}\right) = 41.81^\circ$$

$$\theta_2 = \Phi - \theta_3 = 60^\circ - 41.81^\circ = 18.19^\circ$$

$$\theta_1 = \arcsin(n \sin \theta_2) = \arcsin(1.50 \sin 18.19^\circ) = 27.92^\circ$$

Bonus:

Since the angle of incidence is less than 27.92° , the ray will undergo total internal reflection at the other side of the prism. When it reaches the bottom side, it will exit according to Snell's Law.

$$\theta_2 = \arcsin\left(\frac{1}{n} \sin \theta_1\right) = \arcsin\left(\frac{1}{1.5} \sin 20^\circ\right) = 13.18^\circ$$

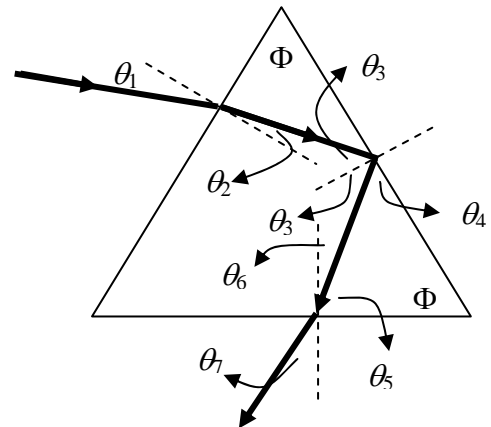
$$\theta_3 = \Phi - \theta_2 = 60^\circ - 13.18^\circ = 46.82^\circ$$

$$\theta_4 = 90^\circ - \theta_3 = 90^\circ - 46.82^\circ = 43.18^\circ$$

$$\theta_5 = 180^\circ - 60^\circ - \theta_4 = 76.82^\circ$$

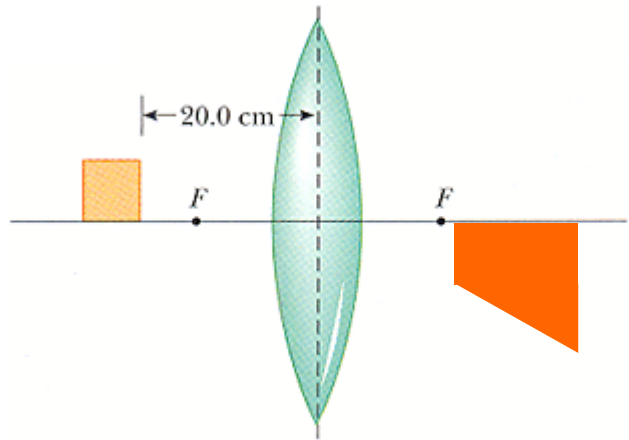
$$\theta_6 = 90^\circ - \theta_5 = 13.18^\circ$$

$$\theta_7 = \arcsin(n \sin \theta_6) = \arcsin(1.50 \sin 13.18^\circ) = 20^\circ$$



Problem 3:

Figure on the right shows a thin glass ($n = 1.45$) converging lens for which the radii of curvature are $R_1 = 15.0$ cm and $R_2 = -13$ cm. To the left of the lens is a cube having a face area of 100 cm². The base of the cube is on the axis of the lens, and the right face is 20.0 cm to the left of the lens.



- (a) Determine the focal length of the lens.
 (b) Draw the image of the square face formed by the lens, by determining the following characteristics of the image.

	position (cm)	magnitude of height (cm)	Is it inverted?
left face	31.97	10.7	Y
right face	68.50	34.3	Y

$$(a) f = \left[(n-1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right) \right]^{-1} = \left[(1.45-1) \left(\frac{1}{15} - \frac{1}{-13} \right) \right]^{-1} = 15.48 \text{ cm}$$

- (b) For the left face of the cube:

$$p_L = 20 + 10 = 30 \text{ cm} \cdot \frac{1}{q_L} = \frac{1}{f} - \frac{1}{p_L} \text{ and } \boxed{q_L = 31.97 \text{ cm}}$$

$$M_L = -\frac{q_L}{p_L} = -1.07, \quad \boxed{h_L = (10 \text{ cm})M_L = -10.7 \text{ cm}}$$

For the right face of the cube:

$$p_R = 20 \text{ cm} \cdot \frac{1}{q_R} = \frac{1}{f} - \frac{1}{p_R} \text{ and } \boxed{q_R = 68.50 \text{ cm}}$$

$$M_R = -\frac{q_R}{p_R} = -3.43, \quad \boxed{h_R = (10 \text{ cm})M_R = -34.3 \text{ cm}}$$

Multiple Choice Questions:

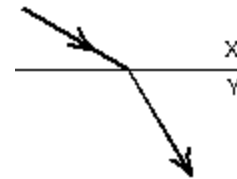
1. Select the correct statement:
 - a) ultraviolet light has a longer wavelength than infrared
 - b) blue light has a higher frequency than x rays
 - c) radio waves have higher frequency than gamma rays
 - d) gamma rays have higher frequency than infra-red waves
 - e) electrons are a type of electromagnetic wave

Gamma rays have the highest frequency and the shortest wavelength of all the waves mentioned. Electrons are charge carrying particles. They produce EM waves when they accelerate.

2. As used in the laws of reflection and refraction, the "normal" direction is:
 - a) any convenient direction
 - b) tangent to the interface
 - c) along the incident ray
 - d) perpendicular to the electric field vector of the light
 - e) perpendicular to the interface

The surface normal is defined to be perpendicular to the interface.

3. When light travels from medium X to medium Y as shown:
 - a) both the speed and the frequency decrease
 - b) both the speed and the frequency increase
 - c) both the speed and the wavelength decrease
 - d) both the speed and the wavelength increase
 - e) both the wavelength and the frequency are unchanged



The light bends towards the normal meaning that the index of refraction in Y is larger than X. This means that both the wavelength and the speed decrease.

4. An erect object is located between a concave mirror and its focal point. Its image is:
 - a) real, erect, and larger than the object
 - b) real, inverted, and larger than the object
 - c) virtual, erect, and larger than the object
 - d) virtual, inverted, and larger than the object
 - e) virtual, erect, and smaller than the object

When the object is closer to a concave mirror than its focal length, the image is virtual and erect and magnified.

5. Which of the following is NOT correct for a simple magnifying glass?
- a) the image is virtual
 - b) the image is erect
 - c) the image is larger than the object
 - d) the object is inside the focal point
 - e) the lens is diverging

A simple magnifier is a converging lens.