## Physics 111

Fall 2007

## Reflection, Refraction and Optical Instruments

1. A narrow beam of ultrasonic waves reflects off the liver tumor shown on the right. The speed of the wave is $10.0 \%$ less in the liver than in the surrounding medium. Determine the depth of the tumor.

2. The light beam shown in the figure on the right makes an angle of $20.0^{\circ}$ with the normal line $N N^{\prime}$ in the linseed oil. Determine the angles $\theta$ and $\theta^{\prime}$. (Note: The index of refraction of linseed oil is 1.48.)

3. Consider a convex lens of focal length 20 cm . Calculate the image distance for each of the following object distances: $\infty, 4 \mathrm{~m}, 2 \mathrm{~m}, 1 \mathrm{~m}, 80 \mathrm{~cm}, 60 \mathrm{~cm}, 40 \mathrm{~cm}, 20 \mathrm{~cm}$.
4. A camera has a lens with adjustable position. The camera depth $d=4 \mathrm{~cm}$. Determine the focal length of the lens and the necessary allowable extension of the lens, $x$, in order that the camera be able to take sharp photographs of objects positioned anywhere from 50 cm to infinity, measured from the front surface of the camera body.

5. A movie star catches a reporter shooting pictures of her at home. She claims the reporter was trespassing. To prove her point, she gives as evidence the film she seized. Her $1.75-\mathrm{m}$ height is 8.25 mm high on the film, and the focal length of the camera lens was 210 mm . How far away from the subject was the reporter standing?
6. A small object is 25.0 cm from a diverging lens as shown in the figure below. A converging lens with a focal length of 12.0 cm is 30.0 cm to the right of the diverging lens. The two-lens system forms a real inverted image 17.0 cm to the right of the converging lens. What is the focal length of the diverging lens?

7. A narrow pencil of light strikes the side of a rectangular fish tank at an angle of $30^{\circ}$ below the horizontal as shown.
(a) What angle does the light ray make with the horizontal in the glass, assuming a 1.55 index of refraction?
(b) What angle does it make in the water?
(c) If the glass wall is 5 mm thick, by what distance is the exit spot inside the glass wall displaced from the location at which the incident beam is aimed?

8. A light ray enters a rectangular block of plastic at an angle $\theta_{1}=45.0^{\circ}$ and emerges at an angle $\theta_{2}=76.0^{\circ}$ as shown in the figure below.
(a) Determine the index of refraction of the plastic.
(b) If the light ray enters the plastic at a point $L=50.0 \mathrm{~cm}$ from the bottom edge, how long does it take the light ray to travel through the plastic?

9. A major problem with larger diameter fibers is the difference in travel times of rays along a fiber. In traveling a distance $d$, the shortest time is that of the axial beam $t_{1}=$ $d / \mathrm{v}$, while the longest time $t_{2}$ is that of a ray bouncing back and forth along the fiber just at the critical angle. Compute the time difference between these two rays for a 1.5 index fiber that is 10 km long, surrounded by 1.49 index cladding. This effectively limits the frequency of a signal that can be transmitted without significant degradation in larger diameter fibers. Small diameter ( $\sim 10 \mu \mathrm{~m}$ diameter) single-mode fibers, in which the light travels as a wave and not as a geometrical ray, overcome this problem.
10. (a) Show that the lens equation can be written in the Newtonian form

$$
x x^{\prime}=f^{2},
$$

where $x$ is the distance of the object from the focal point on the front side of the lens, and $x^{\prime}$ is the distance of the image to the focal point on the other side of the lens. Calculate the location of an image if the object is placed 45.0 cm in front of a convex lens with a focal length $f$ of 32.0 cm using (b) the standard form of the thin lens equation, and (c) the Newtonian form, stated above.
11. You are designing an endoscope for use inside an air-filled body cavity. A lens at the end of the endoscope will form an image covering the end of a bundle of optical fibers. This image will then be carried by the optical fibers to an eyepiece lens at the outside end of the fiberscope. The radius of the bundle is 1.00 mm . The scene within the body that is to appear within the image fills a circle of radius 6.00 cm . The lens will be located 5.00 cm from the tissues you wish to observe.
(a) How far should the lens be located from the end of an optical fiber bundle?
(b) What is the focal length of the lens required?
12. Consider the endoscope probe used for treating hydrocephalus and shown in the figure on the right. The spherical end, with refractive index 1.50, is attached to an optical fiber bundle of radius 1.00 mm , which is smaller than the radius of the sphere. The center of the spherical end is on the central axis of the bundle. Consider laser light that travels precisely parallel to the central axis of the bundle and then refracts out from the surface of the sphere into air.
(a) In the figure, does light that refracts out of the sphere and travels toward the upper right come from the top half of the sphere or from the bottom half of the sphere?
(b) If laser light that travels along the edge of the optical fiber bundle refracts out of the sphere tangent to the surface of the sphere, what is the radius of the sphere?
(c) Find the angle of deviation of the ray considered in part (b), that is, the angle by which its direction changes as it leaves the sphere.
(d) Show that the ray considered in part (b) has a greater angle of deviation than any other ray. Show that the light from all parts of the optical fiber bundle
does not refract out of the sphere with spherical symmetry, but rather fills a cone around the forward direction. Find the angular diameter of the cone.
(e) In reality, however, laser light can diverge from the sphere with approximate spherical symmetry. What considerations that we have not addressed will lead to this approximate spherical symmetry in practice?

