Physics 123, Spring 2009
Homework #5
Due in P123 homework locker 4pm, Friday, March 6, 2009

Feel free to discuss the problems with me and/or each other. Each student must write up his/her own solutions separately.
Unless otherwise indicated, problems are from Giancoli, 4th edition.

Note: If you don't have a copy of volume II of Giancoli, you can find the following questions and problems on the appended pages.

1. Giancoli, chapter 32, question 11, page 859.
2. Giancoli, chapter 32, question 16, page 859.
3. Giancoli, chapter 32, problem 36, page 861.
4. Giancoli, chapter 32, problem 38, page 861.
5. Giancoli, chapter 32, problem 42, page 861.
6. Giancoli, chapter 32, problem 43, page 861.
7. Giancoli, chapter 32, problem 49, page 862.

The frequency or wavelength of light determines its color. The **visible spectrum** in air extends from about 400 nm (violet) to about 750 nm (red).

Glass prisms break white light down into its constituent colors because the index of refraction varies with wavelength, a phenomenon known as **dispersion**.

When light rays reach the boundary of a material where the index of refraction decreases, the rays will be **totally internally reflected** if the incident angle, θ_1, is such that Snell's law would predict $\sin\theta_2 > 1$. This occurs if θ_1 exceeds the critical angle θ_C given by

$$\sin\theta_C = \frac{n_2}{n_1}. \qquad \text{(32–7)}$$

Questions

1. What would be the appearance of the Moon if it had (*a*) a rough surface; (*b*) a polished mirrorlike surface?
2. Archimedes is said to have burned the whole Roman fleet in the harbor of Syracuse by focusing the rays of the Sun with a huge spherical mirror. Is this† reasonable?
3. What is the focal length of a plane mirror? What is the magnification of a plane mirror?
4. An object is placed along the principal axis of a spherical mirror. The magnification of the object is −3.0. Is the image real or virtual, inverted or upright? Is the mirror concave or convex? On which side of the mirror is the image located?
5. Using the rules for the three rays discussed with reference to Fig. 32–15, draw ray 2 for Fig. 32–19b.
6. Does the mirror equation, Eq. 32–2, hold for a plane mirror? Explain.
7. If a concave mirror produces a real image, is the image necessarily inverted?
8. How might you determine the speed of light in a solid, rectangular, transparent object?
9. When you look at the Moon's reflection from a ripply sea, it appears elongated (Fig. 32–41). Explain.

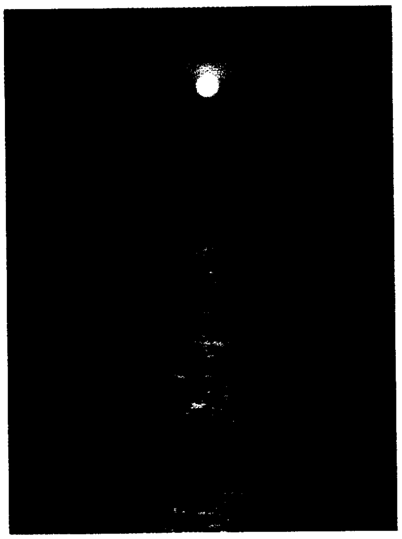

FIGURE 32–41 Question 9.

10. How can a spherical mirror have a negative object distance?
11. What is the angle of refraction when a light ray is incident perpendicular to the boundary between two transparent materials?
12. When you look down into a swimming pool or a lake, are you likely to overestimate or underestimate its depth? Explain. How does the apparent depth vary with the viewing angle? (Use ray diagrams.)
13. Draw a ray diagram to show why a stick or straw looks bent when part of it is under water (Fig. 32–23).

†Students at MIT did a feasibility study. See www.mit.edu.

14. When a wide beam of parallel light enters water at an angle, the beam broadens. Explain.
15. You look into an aquarium and view a fish inside. One ray of light from the fish as it emerges from the tank is shown in Fig. 32–42. The apparent position of the fish is also shown. In the drawing, indicate the approximate position of the actual fish. Briefly justify your answer.

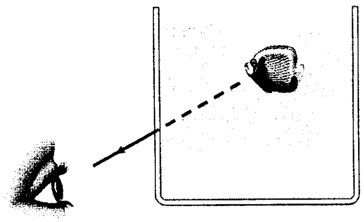

FIGURE 32–42 Question 15.

16. How can you "see" a round drop of water on a table even though the water is transparent and colorless?
17. A ray of light is refracted through three different materials (Fig. 32–43). Rank the materials according to their index of refraction, least to greatest.

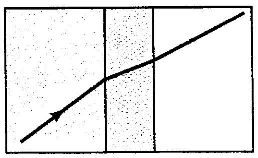

FIGURE 32–43 Question 17.

18. Can a light ray traveling in air be totally reflected when it strikes a smooth water surface if the incident angle is chosen correctly? Explain.
19. When you look up at an object in air from beneath the surface in a swimming pool, does the object appear to be the same size as when you see it directly in air? Explain.
20. What type of mirror is shown in Fig. 32–44?

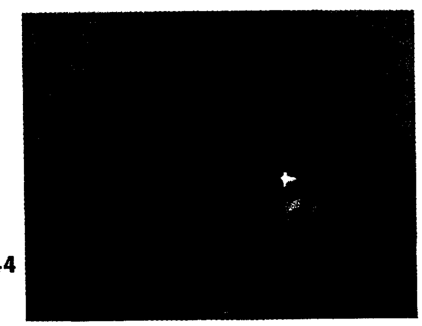

FIGURE 32–44 Question 20.

21. Light rays from stars (including our Sun) always bend toward the vertical direction as they pass through the Earth's atmosphere. (*a*) Why does this make sense? (*b*) What can you conclude about the apparent positions of stars as viewed from Earth?

24. (II) (*a*) Where should an object be placed in front of a concave mirror so that it produces an image at the same location as the object? (*b*) Is the image real or virtual? (*c*) Is the image inverted or upright? (*d*) What is the magnification of the image?

25. (II) A 4.5-cm tall object is placed 26 cm in front of a spherical mirror. It is desired to produce a virtual image that is upright and 3.5 cm tall. (*a*) What type of mirror should be used? (*b*) Where is the image located? (*c*) What is the focal length of the mirror? (*d*) What is the radius of curvature of the mirror?

26. (II) A shaving or makeup mirror is designed to magnify your face by a factor of 1.35 when your face is placed 20.0 cm in front of it. (*a*) What type of mirror is it? (*b*) Describe the type of image that it makes of your face. (*c*) Calculate the required radius of curvature for the mirror.

27. (II) A concave mirror has focal length f. When an object is placed a distance $d_o > f$ from this mirror, a real image with magnification m is formed. (*a*) Show that $m = f/(f - d_o)$. (*b*) Sketch m vs. d_o over the range $f < d_o < +\infty$ where $f = 0.45$ m. (*c*) For what value of d_o will the real image have the same (lateral) size as the object? (*d*) To obtain a real image that is much larger than the object, in what general region should the object be placed relative to the mirror?

28. (II) Let the focal length of a convex mirror be written as $f = -|f|$. Show that the magnification m of an object a distance d_o from this mirror is given by $m = |f|/(d_o + |f|)$. Based on this relation, explain why your nose looks bigger than the rest of your face when looking into a convex mirror.

29. (II) A spherical mirror of focal length f produces an image of an object with magnification m. (*a*) Show that the object is a distance $d_o = f\left(1 - \frac{1}{m}\right)$ from the reflecting side of the mirror. (*b*) Use the relation in part (*a*) to show that, no matter where an object is placed in front of a convex mirror, its image will have a magnification in the range $0 \leq m \leq +1$.

30. (III) An object is placed a distance r in front of a wall, where r exactly equals the radius of curvature of a certain concave mirror. At what distance from the wall should this mirror be placed so that a real image of the object is formed on the wall? What is the magnification of the image?

31. (III) A short thin object (like a short length of wire) of length ℓ is placed along the axis of a spherical mirror (perpendicular to the glass surface). Show that its image has length $\ell' = m^2\ell$ so the *longitudinal magnification* is equal to $-m^2$ where m is the normal "lateral" magnification, Eq. 32–3. Why the minus sign? [*Hint*: Find the image positions for both ends of the wire, and assume ℓ is very small.]

32–4 Index of Refraction

32. (I) The speed of light in ice is 2.29×10^8 m/s. What is the index of refraction of ice?

33. (I) What is the speed of light in (*a*) ethyl alcohol, (*b*) lucite, (*c*) crown glass?

34. (I) Our nearest star (other than the Sun) is 4.2 light years away. That is, it takes 4.2 years for the light to reach Earth. How far away is it in meters?

35. (I) How long does it take light to reach us from the Sun, 1.50×10^8 km away?

36. (II) The speed of light in a certain substance is 88% of its value in water. What is the index of refraction of that substance?

37. (II) Light is emitted from an ordinary lightbulb filament in wave-train bursts of about 10^{-8} s in duration. What is the length in space of such wave trains?

32–5 Snell's Law

38. (I) A diver shines a flashlight upward from beneath the water at a 38.5° angle to the vertical. At what angle does the light leave the water?

39. (I) A flashlight beam strikes the surface of a pane of glass ($n = 1.56$) at a 63° angle to the normal. What is the angle of refraction?

40. (I) Rays of the Sun are seen to make a 33.0° angle to the vertical beneath the water. At what angle above the horizon is the Sun?

41. (I) A light beam coming from an underwater spotlight exits the water at an angle of 56.0°. At what angle of incidence did it hit the air–water interface from below the surface?

42. (II) A beam of light in air strikes a slab of glass ($n = 1.56$) and is partially reflected and partially refracted. Determine the angle of incidence if the angle of reflection is twice the angle of refraction.

43. (II) A light beam strikes a 2.0-cm-thick piece of plastic with a refractive index of 1.62 at a 45° angle. The plastic is on top of a 3.0-cm-thick piece of glass for which $n = 1.47$. What is the distance D in Fig. 32–48?

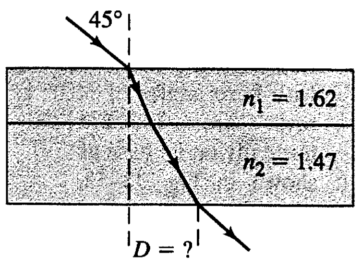

FIGURE 32–48 Problem 43.

44. (II) An aquarium filled with water has flat glass sides whose index of refraction is 1.56. A beam of light from outside the aquarium strikes the glass at a 43.5° angle to the perpendicular (Fig. 32–49). What is the angle of this light ray when it enters (*a*) the glass, and then (*b*) the water? (*c*) What would be the refracted angle if the ray entered the water directly?

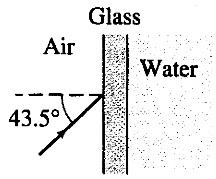

FIGURE 32–49 Problem 44.

45. (II) In searching the bottom of a pool at night, a watchman shines a narrow beam of light from his flashlight, 1.3 m above the water level, onto the surface of the water at a point 2.5 m from his foot at the edge of the pool (Fig. 32–50). Where does the spot of light hit the bottom of the pool, measured from the bottom of the wall beneath his foot, if the pool is 2.1 m deep?

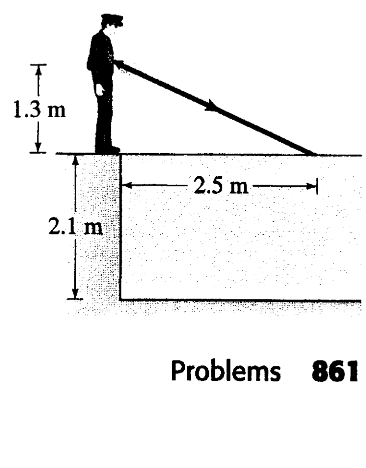

FIGURE 32–50 Problem 45.

46. (II) The block of glass ($n = 1.5$) shown in cross section in Fig. 32–51 is surrounded by air. A ray of light enters the block at its left-hand face with incident angle θ_1 and reemerges into the air from the right-hand face directed parallel to the block's base. Determine θ_1.

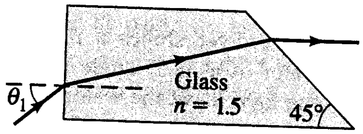

FIGURE 32–51 Problem 46.

47. (II) A laser beam of diameter $d_1 = 3.0\,\text{mm}$ in air has an incident angle $\theta_1 = 25°$ at a flat air–glass surface. If the index of refraction of the glass is $n = 1.5$, determine the diameter d_2 of the beam after it enters the glass.

48. (II) Light is incident on an equilateral glass prism at a 45.0° angle to one face, Fig. 32–52. Calculate the angle at which light emerges from the opposite face. Assume that $n = 1.54$.

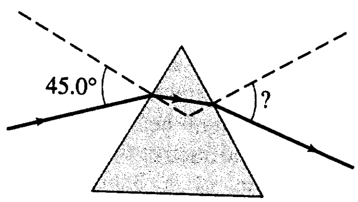

FIGURE 32–52 Problems 48 and 65.

49. (II) A triangular prism made of crown glass ($n = 1.52$) with base angles of 30.0° is surrounded by air. If parallel rays are incident normally on its base as shown in Fig. 32–53, what is the angle ϕ between the two emerging rays?

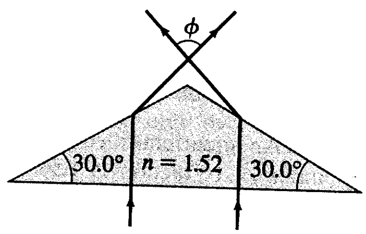

FIGURE 32–53 Problem 49.

50. (II) Show in general that for a light beam incident on a uniform layer of transparent material, as in Fig. 32–24, the direction of the emerging beam is parallel to the incident beam, independent of the incident angle θ. Assume the air on the two sides of the transparent material is the same.

51. (III) A light ray is incident on a flat piece of glass with index of refraction n as in Fig. 32–24. Show that if the incident angle θ is small, the emerging ray is displaced a distance $d = t\theta(n-1)/n$, where t is the thickness of the glass, θ is in radians, and d is the perpendicular distance between the incident ray and the (dashed) line of the emerging ray (Fig. 32–24).

32–6 Visible Spectrum; Dispersion

52. (I) By what percent is the speed of blue light (450 nm) less than the speed of red light (680 nm), in silicate flint glass (see Fig. 32–28)?

53. (I) A light beam strikes a piece of glass at a 60.00° incident angle. The beam contains two wavelengths, 450.0 nm and 700.0 nm, for which the index of refraction of the glass is 1.4831 and 1.4754, respectively. What is the angle between the two refracted beams?

54. (II) A parallel beam of light containing two wavelengths, $\lambda_1 = 465\,\text{nm}$ and $\lambda_2 = 652\,\text{nm}$, enters the silicate flint glass of an equilateral prism as shown in Fig. 32–54. At what angle does each beam leave the prism (give angle with normal to the face)? See Fig. 32–28.

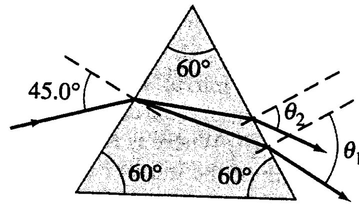

FIGURE 32–54 Problem 54.

55. (III) A ray of light with wavelength λ is incident from air at precisely 60° ($= \theta$) on a spherical water drop of radius r and index of refraction n (which depends on λ). When the ray reemerges into the air from the far side of the drop, it has been deflected an angle ϕ from its original direction as shown in Fig. 32–55. By how much does the value of ϕ for violet light ($n = 1.341$) differ from the value for red light ($n = 1.330$)?

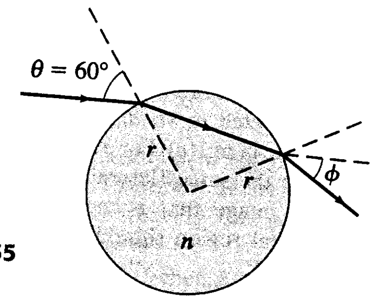

FIGURE 32–55 Problem 55.

56. (III) For visible light, the index of refraction n of glass is roughly 1.5, although this value varies by about 1% across the visible range. Consider a ray of white light incident from air at angle θ_1 onto a flat piece of glass. (*a*) Show that, upon entering the glass, the visible colors contained in this incident ray will be dispersed over a range $\Delta\theta_2$ of refracted angles given approximately by

$$\Delta\theta_2 \approx \frac{\sin\theta_1}{\sqrt{n^2 - \sin^2\theta_1}} \frac{\Delta n}{n}.$$

[*Hint*: For x in radians, $(d/dx)(\sin^{-1}x) = 1/\sqrt{1-x^2}$.] (*b*) If $\theta_1 = 0°$, what is $\Delta\theta_2$ in degrees? (*c*) If $\theta_1 = 90°$, what is $\Delta\theta_2$ in degrees?

32–7 Total Internal Reflection

57. (I) What is the critical angle for the interface between water and diamond? To be internally reflected, the light must start in which material?

58. (I) The critical angle for a certain liquid–air surface is 49.6°. What is the index of refraction of the liquid?

59. (II) A beam of light is emitted in a pool of water from a depth of 72.0 cm. Where must it strike the air–water interface, relative to the spot directly above it, in order that the light does *not* exit the water?

60. (II) A ray of light, after entering a light fiber, reflects at an angle of 14.5° with the long axis of the fiber, as in Fig. 32–56. Calculate the distance along the axis of the fiber that the light ray travels between successive reflections off the sides of the fiber. Assume that the fiber has an index of refraction of 1.55 and is $1.40 \times 10^{-4}\,\text{m}$ in diameter.

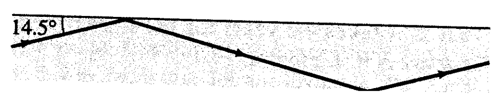

FIGURE 32–56 Problem 60.