Physics 123, Spring 2009
Homework #4
Due in P123 homework locker 4pm, Friday, February 20, 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 3, page 859.
2. Giancoli, chapter 32, question 4, page 859.
3. Giancoli, chapter 32, problem 12, page 860.
4. Giancoli, chapter 32, problem 19, page 860.
5. Giancoli, chapter 32, problem 24, page 861.
6. Giancoli, chapter 32, problem 27, page 861.

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

$$\sin\theta_C = \frac{n_2}{n_1}. \tag{32–7}$$

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.

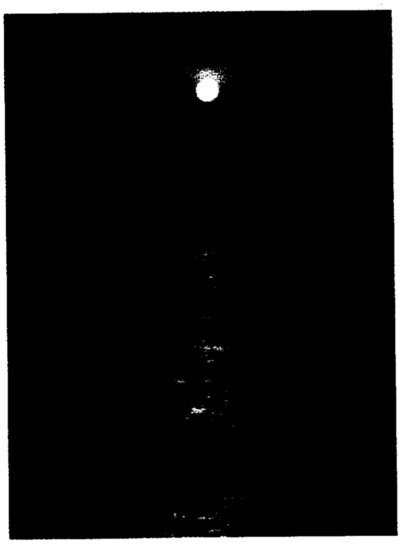

FIGURE 32–41
Question 9.

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.

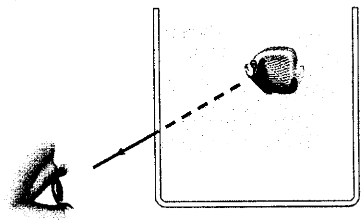

FIGURE 32–42
Question 15.

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.

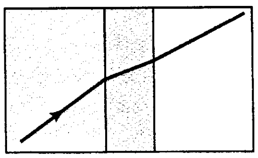

FIGURE 32–43
Question 17.

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?

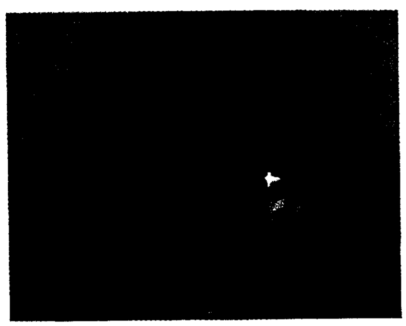

FIGURE 32–44
Question 20.

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?

Problems

32–2 Reflection; Plane Mirrors

1. (I) When you look at yourself in a 60-cm-tall plane mirror, you see the same amount of your body whether you are close to the mirror or far away. (Try it and see.) Use ray diagrams to show why this should be true.

2. (I) Suppose that you want to take a photograph of yourself as you look at your image in a mirror 2.8 m away. For what distance should the camera lens be focused?

3. (II) Two plane mirrors meet at a 135° angle, Fig. 32–45. If light rays strike one mirror at 38° as shown, at what angle ϕ do they leave the second mirror?

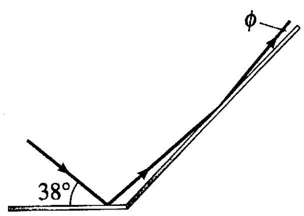

FIGURE 32–45 Problem 3.

4. (II) A person whose eyes are 1.64 m above the floor stands 2.30 m in front of a vertical plane mirror whose bottom edge is 38 cm above the floor, Fig. 32–46. What is the horizontal distance x to the base of the wall supporting the mirror of the nearest point on the floor that can be seen reflected in the mirror?

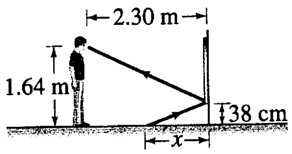

FIGURE 32–46 Problem 4.

5. (II) Show that if two plane mirrors meet at an angle ϕ, a single ray reflected successively from both mirrors is deflected through an angle of 2ϕ independent of the incident angle. Assume $\phi < 90°$ and that only two reflections, one from each mirror, take place.

6. (II) Suppose you are 88 cm from a plane mirror. What area of the mirror is used to reflect the rays entering one eye from a point on the tip of your nose if your pupil diameter is 4.5 mm?

7. (II) Stand up two plane mirrors so they form a 90.0° angle as in Fig. 32–47. When you look into this double mirror, you see yourself as others see you, instead of reversed as in a single mirror. Make a ray diagram to show how this occurs.

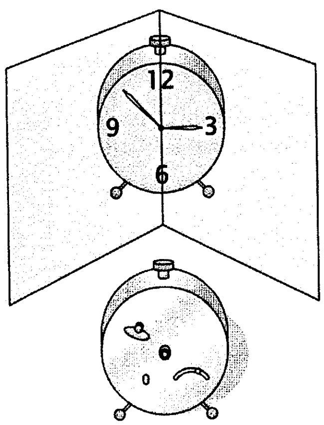

FIGURE 32–47 Problems 7 and 8.

8. (III) Suppose a third mirror is placed beneath the two shown in Fig. 32–47, so that all three are perpendicular to each other. (*a*) Show that for such a "corner reflector," any incident ray will return in its original direction after three reflections. (*b*) What happens if it makes only two reflections?

32–3 Spherical Mirrors

9. (I) A solar cooker, really a concave mirror pointed at the Sun, focuses the Sun's rays 18.8 cm in front of the mirror. What is the radius of the spherical surface from which the mirror was made?

10. (I) How far from a concave mirror (radius 24.0 cm) must an object be placed if its image is to be at infinity?

11. (I) When walking toward a concave mirror you notice that the image flips at a distance of 0.50 m. What is the radius of curvature of the mirror?

12. (II) A small candle is 35 cm from a concave mirror having a radius of curvature of 24 cm. (*a*) What is the focal length of the mirror? (*b*) Where will the image of the candle be located? (*c*) Will the image be upright or inverted?

13. (II) You look at yourself in a shiny 9.2-cm-diameter Christmas tree ball. If your face is 25.0 cm away from the ball's front surface, where is your image? Is it real or virtual? Is it upright or inverted?

14. (II) A mirror at an amusement park shows an upright image of any person who stands 1.7 m in front of it. If the image is three times the person's height, what is the radius of curvature of the mirror? (See Fig. 32–44.)

15. (II) A dentist wants a small mirror that, when 2.00 cm from a tooth, will produce a 4.0× upright image. What kind of mirror must be used and what must its radius of curvature be?

16. (II) Some rearview mirrors produce images of cars to your rear that are smaller than they would be if the mirror were flat. Are the mirrors concave or convex? What is a mirror's radius of curvature if cars 18.0 m away appear 0.33 their normal size?

17. (II) You are standing 3.0 m from a convex security mirror in a store. You estimate the height of your image to be half of your actual height. Estimate the radius of curvature of the mirror.

18. (II) An object 3.0 mm high is placed 18 cm from a convex mirror of radius of curvature 18 cm. (*a*) Show by ray tracing that the image is virtual, and estimate the image distance. (*b*) Show that the (negative) image distance can be computed from Eq. 32–2 using a focal length of −9.0 cm. (*c*) Compute the image size, using Eq. 32–3.

19. (II) The image of a distant tree is virtual and very small when viewed in a curved mirror. The image appears to be 16.0 cm behind the mirror. What kind of mirror is it, and what is its radius of curvature?

20. (II) Use two techniques, (*a*) a ray diagram, and (*b*) the mirror equation, to show that the magnitude of the magnification of a concave mirror is less than 1 if the object is beyond the center of curvature C ($d_o > r$), and is greater than 1 if the object is within C ($d_o < r$).

21. (II) Show, using a ray diagram, that the magnification m of a convex mirror is $m = -d_i/d_o$, just as for a concave mirror. [*Hint*: Consider a ray from the top of the object that reflects at the center of the mirror.]

22. (II) Use ray diagrams to show that the mirror equation, Eq. 32–2, is valid for a convex mirror as long as f is considered negative.

23. (II) The magnification of a convex mirror is +0.55× for objects 3.2 m from the mirror. What is the focal length of this mirror?

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?

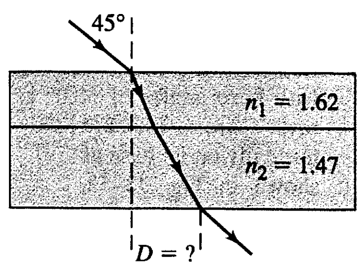

FIGURE 32–48 Problem 43.

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?

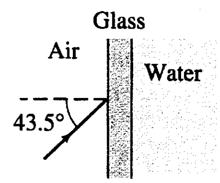

FIGURE 32–49 Problem 44.

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?

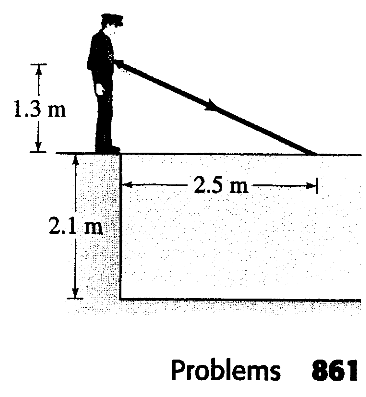

FIGURE 32–50 Problem 45.