World of Light - Problem Set #5

Assigned May 6, due at start of class on ***Wed. May 13***.

Reading

Light Science chapters 3, 4, and 5.

Topics and equations

This problem set revisits several topics that we've discussed before and also covers some new material. Old topics include: shadows, mirrors, lenses, dispersion, real and virtual images, Fermat's principle of least time, photon energy, and water waves. New topics include: Snell's law, total internal reflection, diffraction, interference, polarization, and light momentum. It requires the use of the following constants and equations:

speed of light in vacuum = $c = 3\times10^8$ m/s
acceleration due to gravity = $g = 10$ m/s^2
Planck's constant = $h = 6.6\times10^{-34}$ J s

$$v = \frac{d}{t} \qquad v = \lambda f \qquad v = \sqrt{\frac{\lambda g}{2\pi}} \qquad v = \sqrt{gh} \qquad v = \frac{c}{n}$$

$$a^2 + b^2 = c^2 \qquad n_1 \sin\theta_i = n_2 \sin\theta_t \qquad \theta_c = \arcsin\frac{n_1}{n_2}$$

$$E = hf \qquad p = mv \qquad p = \frac{h}{\lambda}$$

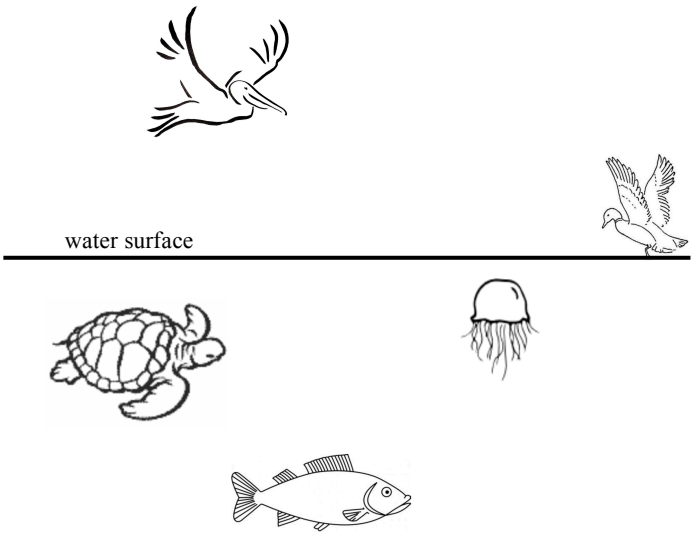
Problems

Grading scale: basically right = 1 point, basically wrong = 0 points, some right and some wrong = 0.5 points.

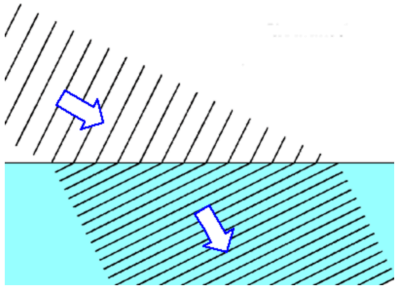
1. Consider the shadow of an object that is formed by direct sunlight. (a) Why is the edge of that shadow somewhat fuzzy, and not totally sharp? (b) Suppose sunlight reflects off of a car windshield, which acts like a convex mirror. Will the virtual image of the sun appear larger or smaller than the actual sun? (c) After reflecting off the windshield, the sunlight forms a shadow of the same object. Will this shadow have a sharper or fuzzier edge? Why?

2. (a) Draw a diagram that illustrates total internal reflection. (b) Write down Snell's law for the case of total internal reflection (e.g. light going from glass to air, angle of transmission equals 90°). (c) Using this equation, what is the critical angle of incidence for light going from glass to air (the index of refraction for glass is 1.5)? (d) What is the critical angle for light going from cubic zirconia to air (this is fake diamond, index of refraction is 2.16)?

3. Consider a sea turtle that's underwater. (a) Can it see everything that is in the air above the water (i.e. the birds shown in the picture)? (b) At what angle away from the vertical does the turtle look to see the feet of the duck that is about to land on the water (assume that the light ray that the turtle sees starts out parallel to the water's surface)? (c) Does the turtle see reflections of anything that's above the water? (d) Can the turtle see everything that is in the water (i.e. the fish and jellyfish)? (e) Does the turtle see reflections of things that are underwater; if so, which ones?

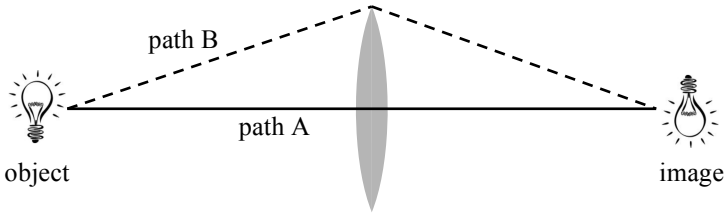


4. Consider *water* waves in 10 m deep water that have a 1 m wavelength. (a) What is the wave speed? (b) What is the wave frequency? These waves come to a region of water that is 5 cm deep, with a 60° angle of incidence (see the figure). (c) What is the wave speed in the shallow water? (d) Defining the refractive index as 1 in deep water, what is the refractive index for the shallow water region (i.e. what is the ratio of wave speeds)? (e) What is the wavelength in shallow water? (f) What is the angle of refraction into the shallow water?

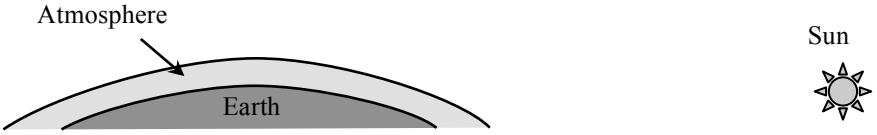


5. Consider light going from an object through a convex lens and then to an image. The lens has a refractive index of 1.5, a radius of 5 cm, a maximum thickness of 1 cm, and a focal length of 26 cm. Suppose the object is 52 cm in front of the lens. *In this problem, compute all times to 3 decimal places*. (a) Where is the image of the object? (b) Is this a real or virtual image? (c) How long does it take light to go from object to image when it goes along the lens axis (path A in the figure)? (d) How long does it take light to go from

object to image when it goes via the lens edge (path B)? (e) Which is faster, or are these the same?



6. The physical sunset time is the time when the top edge of the sun actually goes below the horizon. However, atmospheric refraction causes the sun to appear to set at a slightly different time. In other words, when we look at the setting sun, it appears to be in a slightly different place than where it really is. (a) By drawing rays on the figure, does the setting sun appear to be higher or lower than it really is? (b) Is the apparent sunset time before or after the physical sunset time? (c) The atmosphere has normal dispersion, in which blue light has a higher refractive index than red light. Does the blue sun image set before the red image, or vice versa?



7. Consider a sidewalk section that has an area of 1 m^2 and assume the sun is directly overhead. Also, assuming the sun is beaming primarily green light, which has a wavelength of 500 nm. (a) What is the energy of one sunlight photon? (b) Using the fact that the power of the sunlight on this square meter is about 1367 W, how many photons hit the sidewalk section in one second? (c) What is the momentum of one sunlight photon? (d) What is the momentum of all photons that hit this sidewalk section in one second? (e) Now suppose an ant falls on the sidewalk. A typical ant weighs 4×10^{-6} kg and falls at 1.8 m/s. What is the ant's momentum? (f) Which exerts a greater momentum, the ant or 1 second of sunlight? (g) Which would exert a greater momentum if the sidewalk were silvered, like a mirror?

8. A thin film of oil on water strongly reflects blue light. (a) Draw a diagram that shows the cause of this. (b) Should the oil be made thicker or thinner to reflect red light?

9. Diffraction. (a) Draw a diagram that shows diffraction through a small hole. Now suppose you're in a room which has a 1 meter wide door, which is open, and music is playing outside. (b) What is the behavior of very low notes with ~10 m wavelength (not go in the room, go in the room and travel in a straight line across it, or go in the room and fill the room)? (c) What is the behavior of medium notes with ~1 m wavelength? (d) What is the behavior of very high notes (~10 cm wavelength)?

10. Polarization. (a) Draw a diagram that shows light polarization. (b) Is sunlight polarized? (c) List 3 processes that can be used to polarize light. (d) Can water waves be polarized?