Problem Set 4.2
Sensory Transduction

1. The reference intensity for sound is $10^{-12}\,\mathrm{W\,m^{-2}}$. The density of dry air at 273 K is $1.293\,\mathrm{g\,L^{-1}}$ and the velocity of sound is $331\,\mathrm{m\,s^{-1}}$. This reference intensity corresponds to what maximum pressure amplitude? (Hint: see Eqn [4.7.A1.32]).
2. My old vacuum cleaner makes a noise of about 80 dB. What is the sound intensity? What is the maximum pressure amplitude?
3. Increasing the loudness of a sound from 10 to 20 dB increases the intensity by what factor? It increases the pressure amplitude by what factor?
4. You are subjected to a pure pitch with an amplitude of 40 dB. What is its pressure amplitude? Given that the area of the tympanic membrane is $0.5\,\mathrm{cm^2}$ and that the area of the oval window is $0.03\,\mathrm{cm^2}$, what is the pressure amplitude, assuming no loss during transmission by the ossicles, at the oval window?
5. Assume that the distance between your ears is about 20 cm. Assume that sound waves originate directly to your right. What is the delay in the arrival of the sound between the right and left ear? Do you think that your nervous system could locate the source of sound based on this difference? Why or why not?
6. A. You are looking at an object 1 m tall and 20 m away from you. Assuming the eye is completely relaxed and that the nodal point of the eye is 1.6 cm in front of the retina, calculate the height of the image of the object on the retina, assuming that it is in focus. What is the focal length and the refractive power of the eye under these conditions?
   B. You have shifted your focus to a nearby object 10 cm tall located a mere 0.5 m away. In doing so, your eye accommodates to bring its image into focus on the retina. What is the refractive power of the eye in this case? How tall is the image on the retina?
7. The fovea is responsible for vision of highest acuity, and you move your eyes so as to focus light there. The fovea is about 0.5 mm in diameter. How large an area of attention does this make at 0.5 m distant? At 5 m? 10 m?
8. The resolution of the eye is $1/x$ where x is the spatial separation of a line pair. Typical physiological resolution of the human eye is about 1.7 in good light by this criterion, which corresponds to about 0.6 arc minutes per line pair, or about 0.01. Consider that you are viewing a grating of lines 25 cm from the eye.
   A. If the lines can just be resolved, how large is the distance between line centers?
   B. What is the spacing between the lines in the image on the retina?
   C. In the fovea the light-sensitive areas of the cones are about 1.5×10^{-6} m in diameter and about 2.5×10^{-6} m separates their centers in close hexagonal packing. Does your answer in part B make sense with respect to this spacing of the cones?
9. The energy of a photon of light is given by $E = h\nu$, where h is Planck's constant $= 6.625 \times 10^{-34}$ J s and ν is the frequency of light in $\mathrm{s^{-1}}$. Assume that the average wavelength of light emitted from a normal incandescent bulb is 500 nm = 5000 Å. Assume further that a 100 W bulb's energy is converted 100% to light energy of this wavelength.
   A. How many photons does the bulb emit per second?
   B. Consider that your pupil is constricted to a diameter of 4 mm and that you are 1 m away from the bulb which for this purpose we will consider to be a point source. How many photons enter each of your eyes each second from such a source?
10. Your friend puts on 0.5 mL of a special alluring scent at a concentration of 10 mM of odorant. Assume that all of the odorant is volatilized. What is its final concentration in a room with dimension 11 feet × 15 feet × 8 feet tall? Would you expect to be able to smell this odorant at these concentrations?
11. Two objects are drawn on a sheet of white paper, 4 cm apart, in the horizontal plane. You are instructed to close the right eye and focus on the object to the right, starting with the paper about 30 cm from your eye. As you draw the paper toward you, you notice that at about 13 cm the left object disappears from view! As you draw the paper still closer, it reappears!

DOI: http://dx.doi.org/10.1016/B978-0-12-800883-6.00042-2

Why did it disappear, and then reappear? From the information provided, calculate the angular displacement of the optic nerve from the fovea.

12. To sense any signal, cells must distinguish between the signal and the background noise. For the chemical senses, the signal is the binding of a chemical to a receptor on the sensing cells. At the molecular level, background noise corresponds to thermal fluctuations in the movement of molecules. The equipartition theorem of thermodynamics states that each mode of motion at equilibrium has the energy $\frac{1}{2}kT$, where k is Boltzmann's constant and T is the temperature in Kelvin. $k = 1.38 \times 10^{-23}$ J K^{-1} mol^{-1}.
    A. Calculate the thermal background energy fluctuations, or noise.
    B. Noncovalent binding energies of ligands to their receptors varies with the number of chemical groups on the two surfaces that interact. A typical value is around 10–20 kJ mol^{-1}. How much is this per molecule?
    C. Do you think it is possible to sense the binding of a single ligand?
13. A young adult's eye has a nodal point 1.6 cm in front of the fovea. His near point is 7 cm.
    A. What is his maximum power of refraction?
    B. What is his power of refraction for far objects?
    C. What is his power of accommodation?
14. After increased thirst, increased urination, and increased hunger, the next most common complaint of diabetic persons is blurred vision. Although the cause is still debated, most think that the high plasma glucose causes glucose to enter the lens causing it to swell. What should this swelling do to the refractive power of the lens? What kind of lens is necessary to correct it?
15. Age-related macular degeneration results from atrophy of the retinal pigmented epithelium which causes vision loss through loss of photoreceptor cells. The peripheral retina is unaffected.
    A. What would happen to the ability to read in a person affected by macular degeneration?
    B. What would happen to the ability of a person to walk along a city sidewalk for a person affected by macular degeneration?