Physics 9, Fall 2018, Homework #3.

Due at start of class on Friday, September 28, 2018

Problems marked with (*) must include your own drawing or graph representing the problem and at least one complete sentence describing your reasoning.

Problems for Giancoli Chapter 12 (Sound)

1*. You measure the intensity of a sound wave to be 5.70 W/m^2. If the power output of the signal is 90 W and the signal is emitted in all directions, how far away from the source of the sound are you? (Assume that the sound waves travel outward from the source in spherical wavefronts, and that there are no reflecting surfaces nearby.)

2. Does the inverse-square law for intensity I as a function of distance apply in a small restaurant with hardwood floors; low, flat, drywall ceilings; and hard, uncovered walls? Why or why not?

3. One mosquito flying 0.50 m from a sound level meter emits a sound that has an intensity level of 15 dB. What is the intensity level (in decibels) of the sound emitted by 100 mosquitoes at the same distance? (Since the mosquitoes are not in any way synchronized to each other (they are "incoherent" sources of sound waves), their intensities (not their amplitudes) add up.)

4. Two oboe players are standing side-by-side. One is playing a 247 Hz note, and the other (whose oboe is still cold) is playing a 245 Hz note. What is the beat frequency heard by the audience in the front row?

5*. A piano tuner is adjusting the tension for the string that plays A above middle C on a piano. She strikes her 440 Hz tuning fork, then plays the A_{440} key (with the sustain pedal held down), and hears 3 beats per second. (a) At what two possible frequencies could the piano be string be vibrating? While the string and tuning fork are still vibrating, she very gradually **increases** the tension on the string and hears the beat frequency very gradually decrease from 3 beats per second to 2 beats per second. (b) Now she knows there is only one possible frequency at which the string can be vibrating. What is that frequency?

6. How fast do you have to travel away from a stationary sound source in order for the frequency (a) to be shifted down by 6% (one half-tone lower), (b) to

be halved (one octave lower)? How fast would a moving sound source have to travel away from you for the frequency (c) to be shifted down by 6%, (d) to be halved? Notice that the answers for parts (b) and (d) are not the same, because the equations are different for moving source vs. moving observer. For parts (a) and (c), v/v_{sound} is small enough that the moving-observer and the moving-source equations give very similar results.

7*. A whispering gallery is an elliptically shaped room where a person standing at one focus can hear quite clearly someone speaking very quietly at the other focus. Use the definition of an ellipse and your knowledge of waves to explain how this works. (You might have learned a long time ago that an ellipse is the locus of points such that the sum of the distances to the two foci is a constant.)

8. Suppose that only 0.1% (that's 10^{-3}) of the sound intensity that is incident on the "near" side of a wall makes it through to the "far" side of the wall. (a) What is the "transmission loss" for this wall, in decibels? (b) If the sound intensity on the near side of the wall is 3.2×10^{-7} W/m^2, what will be the sound intensity (due to transmission through the wall) on the far side of the wall?

9. Suppose that the outside wall of your study consists of a thick layer of concrete, so it is very effective at keeping out street noise, except for the window by your desk. When the window is wide open (as if the glass were fully removed), the sound intensity in your room, due to street noise, is 1.6×10^{-7} W/m^2. When the window is fully shut, the sound intensity in your room (due to the same street noise, a fraction of which is transmitted through the glass) is 1.6×10^{-10} W/m^2. (a) What fraction of the incident sound intensity from the street is transmitted through the window glass? (b) What fraction of the incident sound intensity from the street is transmitted into your room when the window is open only 5% of the way? (Then 5% of the window area is fully open, with 100% transmission, while 95% of the window area has the transmission fraction that you found in part (a): the resulting transmission fraction will be an area-weighted average of these two fractions.) (c) Using your answer for (b), what will be the sound intensity in your room (in W/m^2), due to street noise, when the window is 5% open? (d) Convert 1.6×10^{-7} W/m^2 into an "intensity level" in decibels (with respect to the threshold of human hearing). (e) Convert 1.6×10^{-10} W/m^2 into an intensity level in decibels. (f) Convert your answer for part (c) into an intensity level in decibels. (g) Convert your answer for part (a) into a "transmission loss" in decibels. This is a measure of how effective your window is at blocking sound when it is closed. (h) Convert your answer for part (b) into a "transmission loss" in decibels. This is a measure of how effective your window is when it is 5% open.

10. In class, we added a mass to the middle of the wave machine to model the reflection (and partial transmission) of sound through a window or a wall. For a single, uniform sheet of material (glass, drywall, concrete, etc.), this (highly simplified) model predicts that a fraction

$$T = \frac{1}{1 + \left(\frac{\pi\ \mu_{\rm wall}\ f}{v_{\rm sound}\ \rho_{\rm air}}\right)^2} \approx \left(\frac{v_{\rm sound}\ \rho_{\rm air}}{\pi\ \mu_{\rm wall}\ f}\right)^2$$

of the incident power will be transmitted through the wall or window, where $v_{\rm sound} = 343$ m/s is the speed of sound, $\rho_{\rm air} = 1.2\ \mathrm{kg/m^3}$ is the density of air, f is frequency, and μ is the mass per unit area of the wall. So the reduction in sound intensity scales like $\mu^2 f^2$: more massive (per unit area) walls reflect more sound, and higher frequencies are more easily reflected than lower frequencies.

(a) At $f = 500$ Hz, what fraction of incident sound intensity is transmitted through a 6 mm thick glass window? (Use 2500 $\mathrm{kg/m^3}$ for the density of glass.)
(b) At $f = 500$ Hz, what fraction of intensity is transmitted through a 13 mm thick layer of gypsum drywall (density $\approx 750\ \mathrm{kg/m^3}$)?
(c) At $f = 500$ Hz, what fraction of intensity is transmitted through a 15 cm thick layer of concrete (density $\approx 2300\ \mathrm{kg/m^3}$)?
(d) Now express your answers to parts (a), (b), and (c) in decibels. (You will get negative numbers, because the logarithm of a number smaller than 1 is negative. Remember to use base-10 logarithms for decibels.) For comparison, a typical pair or ear plugs has a "noise reduction ratio" of 30 dB, i.e. if you are working in an environment with Intensity Level 70 dB (like being near a vacuum cleaner), with earplugs the Intensity Level reaching your ears will be 40 dB (like being in a reasonably quiet room).

A useful rule of thumb is that doubling the mass-per-unit-area or doubling the frequency reduces the transmitted intensity level by 6 dB, i.e. cuts the transmitted intensity (power per unit area) by a factor of 4. The trick of using two separated walls or windows (which we also showed on the wave machine) gets a much larger reduction for a given amount of mass.

Remember **online response** at `positron.hep.upenn.edu/wja/jitt/?date=2018-09-28`