Physics 100: **Solutions** to Homework Assignment #8

Was Due on Monday, April 9th at the Beginning of Class

Section 1. **Warm-up! Fill-in-the-Blanks (1 pt each)**

1. The setting up of vibrations in an object is known as forced vibration.
2. Sound waves consist of alternating regions of rarefaction and compression of the medium.
3. A reflected sound wave is also known as an echo.
4. The angle of incidence is equal to the angle of reflection for sound waves, and all waves more generally. This is known as the Law of Reflection.
5. The frequency at which an elastic object naturally tends to vibrate if it is disturbed by a force that is removed is it's natural frequency.
6. Constructive interference results from crest-to-crest reinforcement of two overlapping waves. On the other hand, destructive interference results from crest-to-trough cancelation.
7. A series of alternate reinforcements and cancelations produced by the interference of two waves of slightly different frequencies, heard as a throbbing effect in sound waves, is known as beats.
8. Sound waves, like all waves, tend to bend towards regions in space where the waves travel slowly. This is known as refraction.

Section 2. **Short Answer Questions (2 pts. each)**

9. A cat can hear sound frequencies up to 70,000 Hz. Bats send and receive ultrahigh-frequency squeaks up to 120,000 z. Which hears sound of shorter wavelengths, cats or bats?

   Answer:

   The wavelength, speed, and frequency of a wave are all related through the wave equation: $speed = wavelength \times frequency = \lambda \times f$. Assuming that the speed of sound doesn't depend too strongly on the frequency (i.e. the sounds cats and bats hear travel at the same speed), we see that the higher the frequency, the smaller the wavelength. In equation form:

   $$\lambda_{bat}\,\mathbf{f}_{bat} = \lambda_{cat}\,f_{cat}$$

   Therefore, the bat hears sounds of shorter wavelengths than cats can.

10. A sound wave travels through air with a speed of 350 m/s and has a wavelength of 0.7 m. It passes over a tuning fork whose natural frequency exactly matches the frequency of the sound wave. **(A)** What is the natural frequency of the tuning fork? **(B)** In this situation, what will the tuning fork start to do?

    Answer:

    (A) We need to find the frequency of the wave, as it will be the same as the natural frequency of the tuning fork since the tuning fork's natural frequency exactly matches that of the wave. Using the wave equation, $v = \lambda\, f$, we solve for the frequency:

    $$f = \frac{v}{\lambda} = \frac{350\ m/s}{0.7\ m} = 500\ \text{Hz}$$

    So the natural frequency of the tuning fork is also 500 Hz.
    (B) The tuning fork will start vibrating at its natural frequency because it is being pushed and pulled by the sound wave's regions of compression and rarefaction at its natural frequency.

11. You see a bolt of lightning and estimate that it took 2.5 seconds for the thunder to reach you. **(A)** About how far away did the lightning strike? **(B)** Why is it that it takes a fraction of a second for a bolt of lightning to strike, but the thunder can rumble on for many seconds?

    Answer:

    (A) The time lag between the lightning and thunder is due to sound traveling much more slowly than light. The light from the lightning reached your eyes almost instantly, so we can use the fact that sound travels at about 340 m/s and calculate that:

    $$distance = speed \times time = 340\ m/s \times 2.5\ s = 850\ m = 0.52\ miles$$

    You could also use the rule of thumb that for every 5 seconds of waiting, the lightning struck 1 mile away. In this case, you waited 2.5 seconds, so the lightning must have struck 0.5 miles away. Quite close to the other answer!

    (B) The rumble lasts for so long because the bolt of lightning may by a couple of miles long (or more!). Every point along that bolt of lightning creates a sound. The first sound you hear is from the point closest to you– the place where the lightning struck if you're on the ground. The last place you hear sound from is up in the clouds. So if the clouds are 2 miles above your head, it will take several additional seconds for that sound to reach you. So from the first sound you hear for the next several second, you hear rumbling thunder generated from different parts of the lightning bolt. In addition to this, you can get sound reflections (echos) from the clouds and buildings which can make the thunder sound like it's going on for a very, very long time.

12. **(A)** If the moon were to explode, would we hear it? **(B)** Why or why not?

    Answer:

    (A) No.

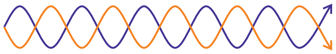
    (B) Sound is a pressure wave. It needs 'stuff[1]' to travel through. Between the Moon and the Earth, there isn't any stuff for sound to travel through, so we won't hear the Moon make any noise even if does explode.

13. **(A)** What kind of waves can exhibit interference? **(B)** When is it possible for one wave to cancel another?

    Answer:

    (A) ALL kinds of waves can exhibit interference!

    (B) When both waves have the same frequency (i.e. wavelength & speed), but are 'anti-phased,' meaning that the crest of one lines up with the trough of the other, as shown below"

14. The sitar, an Indian musical instrument, has a set of strings that vibrate and produce music, even though they are never plucked by the player. These "sympathetic strings" are identical to the plucked strings and are mounted below them. What is your explanation?

    Answer: The sympathetic strings are tuned so that their natural frequencies match those of the plucked strings. When the plucked strings are plucked, they create sound waves with a frequency that matches that of the sympathetic strings' natural frequencies. These sound waves push and pull n the sympathetic strings in exactly the way they like to pushed and pulled on so they start vibrating– they take energy from the sound wave of caused by the plucked strings to do so.

15. How is it that whales can communicate over hundreds of miles using sound waves?

    Answer: They take advantage of the ocean sound channel. The water at the top of the ocean is warmed by the Sun, while the water at the bottom of the ocean is not (it's right near freezing!). Sound travels faster in warm water than cold water, so at first you may think that sound generated in the ocean tends to bend towards the bottom and get absorbed by the sand down there.

---

[1] E.g. air, liquid, solid

However, there is one more effect: the water at the bottom of the ocean is much more compressed than the water at the top of the ocean. The speed of sound in compressed water is higher than the speed of sound in uncompressed water. At large depths, this effect becomes more important than the temperature effect so what ends up happening is that at the top of the ocean, the speed of sound travels faster due to warm water. Deeper down, the temperature of the water drops and the speed of sound decreases. Even deeper, the pressure compresses the water so much that the speed of sound starts to increase again.

The region where sound travels the slowest, typically around 1 km deep, is known as the Ocean Sound Channel, because if sound is created in this layer, the sound waves will become trapped due to refraction: the sound waves moving up bend back down to the low-speed region; the sound waves moving down bend back up to the low-speed region. The net result is that the sound is trapped here and propagates across the ocean, rather than going down to the sandy bottom and being absorbed.

This is depicted in the figure below. Whales can dive to these depths and sing so that their songs are carried across the ocean to other whales.

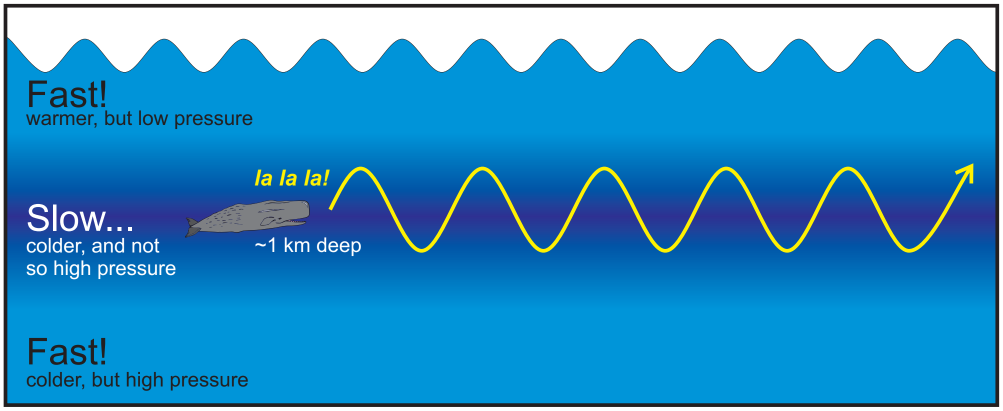


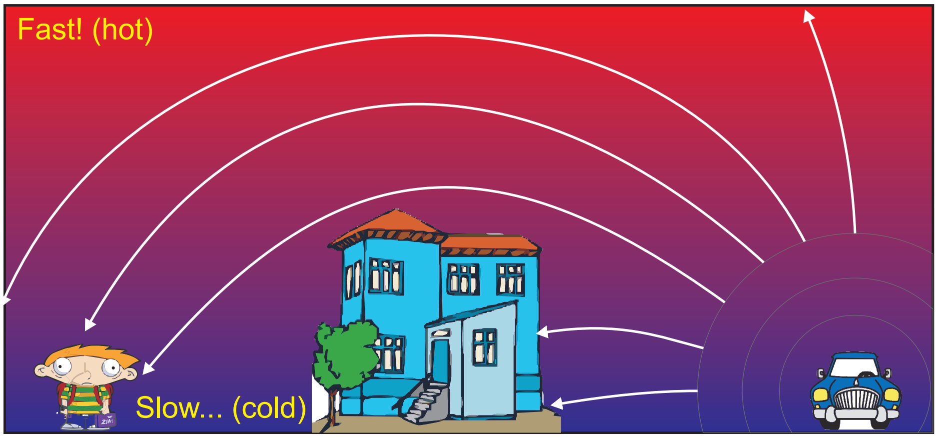
Figure 1: A whale singing in the Ocean Sound Channel. Refraction causes the whale's song to bend towards the part of the ocean where sound travels the slowest, trapping its song in the Ocean Sound Channel so it can travel across the world. Note that the sine wave coming from the whale does not depict the actual crests and troughs of the whale song, but the path the crests and troughs the waves travel on. In other words, you could not determine the wavelength of the whale song from this picture.

16. How can a certain note sung by a singer cause a crystal glass to shatter?

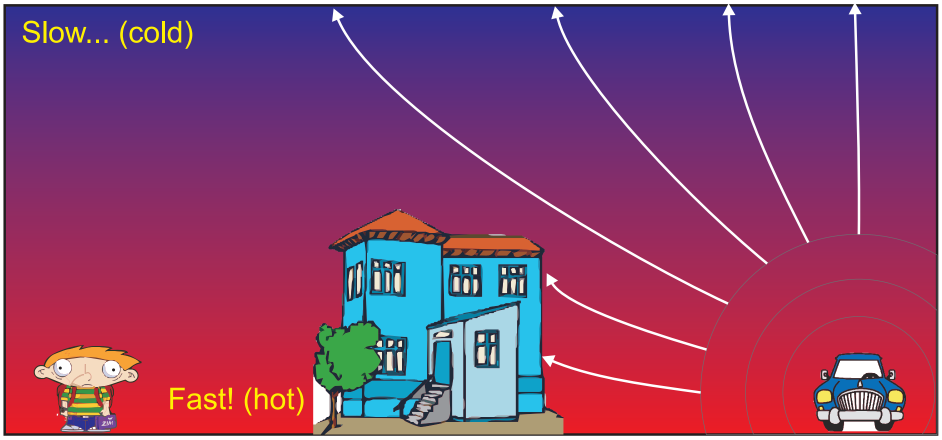
    Answer: The underlying idea is the same as in Problem 14. If the crystal glass is a good quality so that it has a good, well-defined natural frequency, and the opera singer sings at that frequency, her voice will start the glass vibrating. The glass will continue to suck energy out of the opera singer's voice and vibrate with a larger and larger amplitude until it shatters.

17. Inversion layers can dominate local weather, and usually mean hot and smoggy days. On a morning when an inversion layer is in existence, the air near the ground is colder than air a little higher in elevation. How might you use your ears to predict if a day will be hot and smoggy? For more information of inversion layers, see Wikipedia: http://en.wikipedia.org/wiki/Temperature_inversion .

    Answer: Your ears would hear distant traffic more loudly than they would on a normal morning, when the air near the ground would have been warmer than the air above it. This is due to refraction. Sound waves travel slower in colder air and thus tend to bend towards it, as shown below.



(a) You'll know it's going to be smoggy and hot when a late-morning temperature inversion allows you to hear distant traffic! Hot air above cold air bends sound waves back to the ground.



(b) On a normal late-morning, the air near the ground is warmer than the air up higher so sound waves are bent away from the ground!

Figure 2: See Problem 17

18. For which medium will sound travel faster: **(A)** Hot air or cold air? **(B)** Salty water or fresh water? **(C)** Helium gas or CO_2 gas? **(D)** Compressed water or uncompressed water? **(E)** water or air? **(F)** Steel or water?

    Answer:

    (A) Hot air: the air molecules are moving faster so they will bump into each other and transmit the pressure wave faster. A good thing to remember: the speed of sound in a gas is very close to the speed of the gas molecules.
    (B) Salty water; it's denser so the molecules are packed a bit closer and so transmit sound better (kind of more 'rigid').
    (C) Helium gas. Temperature is a measure of kinetic energy. If two gasses have the same temperature, the gas molecules have the same average kinetic energy. Therefore a gas with lighter molecules has faster molecules than a gas with heavier molecules ($\frac{1}{2}\mathbf{M}v^2 = \frac{1}{2}m\mathbf{V}^2$).
    (D) Compressed water; the molecules are pushed together more so compressed water is 'more rigid' than uncompressed water.
    (E) Water; sound travels faster in liquids than gasses.
    (F) Steel; sound travels faster in rigid solids than liquids.

19. A special device can transmit out-of-phase sound from a noisy jackhammer to its operator using earphones. Over the noise of the jackhammer, the operator can easily hear your voice while you are

unable to hear his. Explain.

Answer: The earphones create sound waves that exactly cancel out the jackhammer by inverting the noise from the jackhammer. See Problem 13. So the wearer doesn't hear the jackhammer. The headphones can be designed so they only cancel out the jackhammer so that the wearer could still hear everything else. A person standing next to a jackhammer without these headphones is overwhelmed with the noise and can't hear anything but the jackhammer (and not even that if they don't soon get hearing protection!).

20. **(A)** What physics phenomenon underlies the production of beats? **(B)** A piano tuner using a 264-Hz tuning fork hears four beats per second. What are two possible frequencies of vibration of the piano wire?

Answer:

(A) Interference.
(B) The beat frequency is calculated as:

$$f_{beats} = |f_1 - f_2|$$

If $f_1 = 264\ Hz$ and the beat frequency is $4\ Hz$, then f_2 must be equal to either $268\ Hz$ or $260\ Hz$.

21. **(A)** Do sound waves carry energy and momentum? **(B)** If you answered 'yes' (which you probably should have) give a physical example that demonstrates that they do. **(C)** List two reasons why sound waves get weaker the further you get from their source.

Answer:

(A) Yes.
(B) Sound waves cause your eardrum to vibrate back and forth. When your eardrum changes its speed and direction, it is changing both its momentum and kinetic energy, and they must have come from the sound wave (conservation of momentum and conservation of energy). Thus the sound wave has to carry momentum and energy, otherwise you couldn't hear anything.
(C) 1) The sound waves tend to get absorbed by whatever they're traveling through– some of their energy is converted into heating the medium. 2) The sound waves travel out in all directions, so the energy they carry is spread out more. This means that the amplitude of the sound wave drops as you get further from the source, just as the intensity of a light bulb drops as you get farther from it.