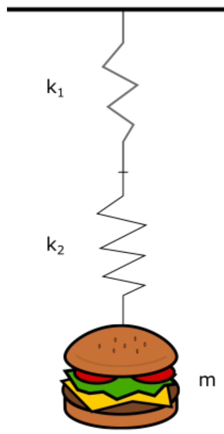
Homework Assignment 8

Due: Monday, August 1, 2016

Problem 1: An object of mass m is suspended from the ceiling by two ideal springs of spring constants k_1 and k_2 connected end to end. To study oscillations of the object, we need the 'effective' spring constant k_{eff} of the spring combination.

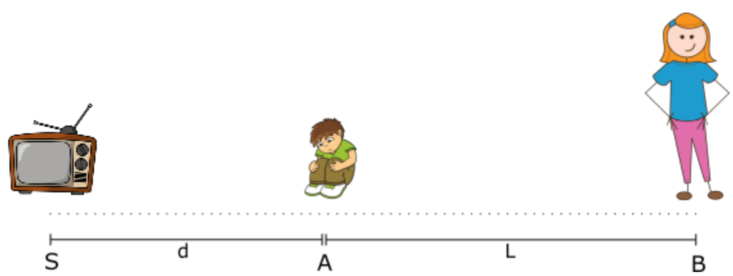


(a) If the spring system is under a tension T, what is the extension (from the relaxed length) in the first spring? What is the extension in the second spring? Assume that the tension is stretching (as opposed to compressive).

(b) What is the total extension from the relaxed position, when the spring system is under tension T? What is k_{eff}? If a single ideal spring of spring constant k_{eff} is used to suspend the object, it will produce the same motion in the object as the combination of the two springs.

(c) Calculate the angular frequency of oscillations of the mass m, is it is displaced by a distance A from it's equilibrium position.

Problem 2: A source of sound (S), listener A and listener B lie on a straight line. A lies between S and B. The distance from S to A is d, and the distance from A to B is L.



(a) If the intensity of sound received by A is I_{A}, what is the intensity received by B?

(b) The source of sound is brought closer to A, and it's volume is reduced in such a way that the intensity received by A remains the same. In other words, d is reduced, keeping I_{A} fixed. What happens to the intensity received by B? If d is halved, by what factor does I_{B} change?

That I_{B} can be reduced while keeping I_{A} fixed is the principle behind earphones.

Problem 3: String Instruments

Each string of a string instrument has a certain mass m and length, and is held at certain tension T. When plucked, the oscillation in the string is a standing wave, which is usually a linear combination of the possible harmonic standing waves (fundamental standing wave, first overtone, etc). Tuning is done by adjusting the tension T in the string (for example, by twisting knobs that tighten or loosen strings). The player can control the length L of the vibrating section of the string when it is plucked or rubbed (e.g., by fretting on a guitar). Let's look at how the instrument sounds for a given fret position (fixed L).

(a) Write the expression for the wavelength of the n^{th} harmonic in terms of m, T, and L. Can you change the wavelengths by tuning, or is it fixed by the fret position?

(b) Write the expression for the speed of oscillations in the string v, in terms of m, T, and L. Can you change this speed by tuning?

When the string vibrates, it sets the surrounding air in vibration at the same frequency as itself, not the same wavelength.

(c) Write the expression for the frequency of the n^{th} harmonic, in terms of m, T and L. Can you change the frequencies by tuning? Do you need to be able to change m and L to achieve the frequency you want, or is changing T sufficient?

(d) $f = \frac{v}{\lambda}$ where v is the speed of oscillations in the string. Which of v and λ was fixed by construction and fret position? Which one can be changed by tuning to achieve the desired frequency?

(e) If the speed of sound in *air* changes, will the frequency of the sound produced change? Will a guitar tuned in your room sound different in an auditorium at different conditions (different temperature, filled with helium, etc)? [Hint: What is v in part d?]

Problem 4: Wind Instruments

A wind instrument is played in a room where the speed of sound, over which you have no control, is v. The effective length of the resonating column is controlled in two ways:

1. By closing holes or pushing keys. This is done during playing, and is analogous to fretting on a guitar.
2. Tuning the instrument. Note that for a given keys/holes choice, the instrument can have different effective lengths depending on tuning.

We'll look at how the instrument sounds for a given choice of keys to press or holes to close. So, L is controlled only by tuning. Although what follows can be generalized to all wind, instruments, we'll pick an ideal instrument whose resonating column is open at both ends.

(a) Write the expression for the wavelength of the n^{th} harmonic in terms of v and L.

(b) Write the expression for the frequency of the n^{th} harmonic in terms of v and L.

(c) If the speed of sound in *air* changes, will the frequency of the sound produced change? Can a saxophone tuned in your room sound different in an auditorium at different conditions (different temperature, filled with helium, etc)? [Hint: Air inside the instrument is *usually* the air in the room]

Additional note: '*Usually* the air in the room'? Larynx aka voice box... wind instrument... helium balloons

Problem 5: Two coherent waves exist in a region of space. Their resultant intensity can be changed by altering the phase difference between them. It is found that by changing the phase difference, the maximum intensity achievable is I_{max} and the minimum intensity achievable is I_{min}. Let the intensities of the individual waves be I_1 and I_2 ($I_1 > I_2$). Given I_{max} and I_{min}, find I_1 and I_2. [Hint: Note that this problem deals with intensities not amplitudes. It maybe easier to solve for A_1 and A_2 in terms of A_{max} and A_{min}.]

Problem 6: A person swallows some helium and tries to speak. In normal air, the speaking attempt would've produced sound at a frequency of 98 Hz. What is the frequency of sound produced when the air flowing through the larynx is helium? What is the frequency and wavelength of sound heard by the listeners in this case, who themselves are surrounded by normal air? Speeds of sound in air and helium are respectively 340 m/s and 1000 m/s. [Hint: When sound is transmitted from one medium to another, what about it remains the same?]

Problem 7: A wave travels along a string and obeys the following equation,

$$y_1(x,t) = (12.0\text{ cm})\cos\left[(3\pi\text{ rad/m})\,x + (12\pi\text{ rad/s})\,t\right].$$

(a) What is the speed of the wave y_1 traveling along the string? In what direction is this wave traveling along the string? What is the maximum speed of the string itself?

(b) A second wave, described by the equation

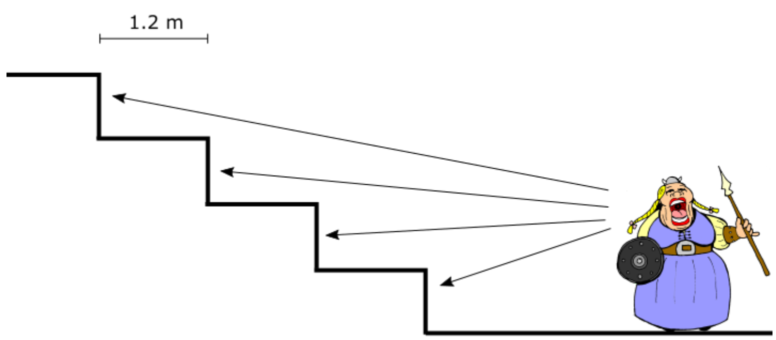
$$y_2(x,t) = (12.0\text{ cm})\cos\left[(3\pi\text{ rad/m})\,x + (12\pi\text{ rad/s})\,t + \frac{\pi}{6}\text{ rad}\right],$$

is added to the string. What is the *distance* between the two nearest crests of the waves y_1 and y_2? [Hint: consider both waves at $t = 0$.]

The wave y_2 is now removed from the string for part (c).

(c) We wish to create a standing wave in the string. Write down the equation for the wave we need to add to the string for a standing wave to form. In what direction does this wave travel, and what is its wavelength? Write down the equation for the standing wave that is formed in the string. What is the distance between any two nodes on the string?

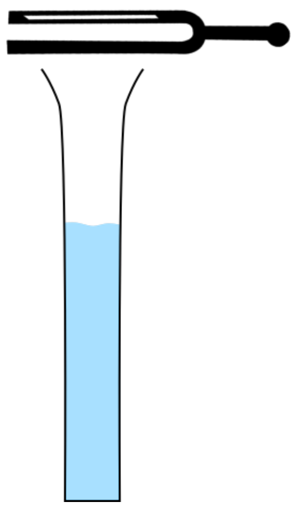
Problem 8: Helga stands on stage in a Greek amphitheater and claps her hands; the sound waves from her clap scatter off of the benches of the theater and return to the stage as a periodic series of sound pulses. The sound echoes off of each bench once and the returning pulses sound like a played note. *Assume the sound waves are purely horizontal* and $v_{\text{sound}} = 340$ m/s.



(a) Find the frequency at which the pulses return (and thusly the frequency of the played note) if each bench has a width of 1.2 m.

(b) If the width of the benches were smaller, would the frequency of the played note be higher or lower?

Problem 9: Bradley wishes to measure the height of the water level in a vertical glass tube. Instead of using a ruler, he decides to calculate the height by using an array of adjustable tuning forks. He strikes a tuning fork and places it directly over the open end of the tube; if the sound generated by the tuning fork resonates in the tube, Bradley makes note of the frequency of that tuning fork. He claims that he can then determine the height of the water level below the lip of the glass tube from this frequency alone.



(a) If a sound of 440 Hz resonates in the tube, what does Bradley claim to be the distance of the water level below the top of the tube? Assume Bradley takes 440 Hz to be the fundamental frequency of the resonance.

(b) Unfortunately for Bradley, 440 Hz is not the only frequency that will resonate in this tube. List three other frequencies that will resonate in the tube. Explain how you got these frequencies.

(c) Assuming the three frequencies from part (b) are fundamental, what are the three distances associated with the other resonant frequencies?

Problem 10: You wish to study for your upcoming physics exam, but your roommate is playing some sweet jazz on her saxophone. She's aware of your plight, and so tries to play quietly–as quietly as possible on a saxophone. Standing 5 m away, her mezzoforte notes still have an intensity level of 80 dB.

(a) Closing the door to your room cuts the intensity of her playing to a third of its initial value. What is the change in intensity level, as measured in dB?

(b) Assuming that the saxophone is an isotropic source of sound, how far away from the instrument would you have to walk to achieve the same level of quiet as in part (a)?

Problem 11: A German submarine and a Russian submarine move toward each other during training maneuvers in motionless water in the North Atlantic. The German sub moves at speed $v_G = 50.0$ km/h, and the Russian sub at speed $v_R = 60.0$ km/h. The Russian sub sends out a sonar signal at 1.00×10^3 Hz. The sonar waves travel at 5470 km/h. What frequency is detected by the Russian sub in the signal reflected back to it by the German sub? [Hint: there are *two* doppler shifts in this problem!]

Problem 12: In tuning a guitar, one string is plucked and allowed to vibrate. The sound generated by the string is then compared to a reference note, usually from a tuning fork or digital tuner. The tension in the guitar string is adjusted so that the played note matches the reference note. Ignore all overtones in this problem.

(a) When you pluck the D-string and compare it to the reference D-note (146.8 Hz), you hear a beat frequency. What does this beat frequency tell you about the two notes.

(b) As you tighten the string, the beat frequency from part (a) decreases. Was the D-string initially tuned too high or too low? Explain.

(c) If the beat frequency in part (a) was initially 1.5 Hz, by what percentage did the tension in the string change in tuning the D-string to match the reference note?