Name: Solutions

Student ID number: ______________________

Oral interview time (see below): ______________________

Discussion section: ____________

MIDTERM 1
PHYSICS 1B, SPRING 2020

APRIL 24, 2020

READ THE FOLLOWING CAREFULLY:

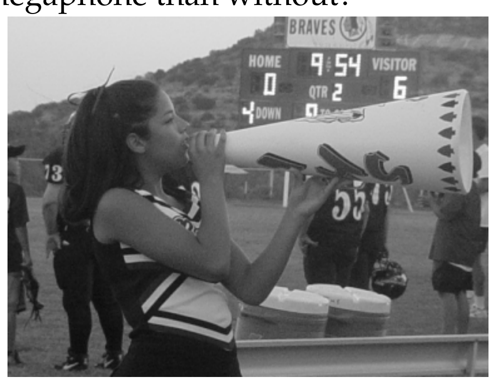
- ▷ Open book. Calculators will not be needed. Make sure that you work independently on the exam, i.e., no discussion with others.
- ▷ Oral interview time: choose a time period of 20 minutes between 11:59AM and 11:59PM on April 25 (Pacific Time) for possible oral interview (via the zoom office hour link). A random sample of students will be selected and be notified via email by 11:59AM on April 25 (Pacific Time). If all of the work on your submission is your own, you will have nothing to worry about.
- ▷ For non-response in the field of oral interview time, I may assess a score penalty.
- ▷ Make sure to submit your exam packet via GradeScope by 9AM April 25, Pacific Time. **No credit will be given for late submissions**.
- ▷ To submit your exam, you have the following two options: (a) Download the PDF from CCLE, print out the PDF, write your solutions in the space provided on the exam packet, scan your packet using a smart phone scanning app such as Adobe Scan, upload your scan to Gradescope. (b) View the PDF on CCLE, write your solutions to all of the problems on loose-leaf, lined or blank paper **in precisely the locations you would have written your responses if that paper were the exam packet**. Scan and upload your packet of solutions to Gradescope.
- ▷ For every option above, **you must make sure that your submission has exactly the same number of pages as the posted exam PDF (including this page)**.
- ▷ **You must justify your answers to each question**. Simply giving the correct answer without proper justification (can be brief) will not result in full credit.
- ▷ Mistakes in grading: If you find a mistake in the grading of your exam, alert the instructor within one week of the exams being returned.

[1.] Short answer conceptual questions. Provide *concise* answers to the questions below; you should write enough to explain your answer, but an essay is not required (most can be answered in $2-3$ sentences).

(a) (8 pts) I have a tuning fork that when struck sounds a perfect middle C (261 Hz). I have an organ pipe, open on both ends whose fundamental frequency is also middle C; when I strike the tuning fork, I can hear the pipe resonate with the sound waves from the fork. I now close off one end of the organ pipe; the fork no longer resonates with the pipe (this makes me sad). A friend, trying to cheer me up, suggests that I could make the fork emit sound waves that again resonate with the tube by running (perhaps very fast) with the fork in hand. Will that work, and if so why and how should I run with the fork?

> When I close off the tube, the frequency of the fundamental standing wave *decreases*. So I need to somehow make the frequency emitted by the fork decrease if I want to drive the fundamental again. I can use the Doppler effect to do this, by running with the fork *away* from the tube. However, you do have to run away quite fast; in order to halve the frequency of the emitted sound, you have to run at the sound speed (make sure you stretch before you try this). You can also argue that by running toward the tube and Doppler upshifting the frequency you can excite a higher harmonic of the closed tube.

(b) (10 pts) **(i)** Give two reasons why the intensity of sound waves from a point source decreases with distance. **(ii)** Why do cheerleaders use megaphones at sporting events (the non-electric kind, see the image below)? If the cheerleader yells at me in the same way with or without the megaphone (that is, the power used in generating the waves is the same in both cases), why would I hear her better with the megaphone than without?



Solution: **(i)** (1) The intensity decreases due to spreading of the power in space; waves travel in all directions from the point source, spreading the power uniformly over a spherical surface. This makes the intensity drop off as $1/r^2$. The second reason is that there may be some damping as the wave travels, also reducing the wave intensity. **(ii)** The megaphone helps direct the sound waves to the listener via reflections off of the walls of the megaphone. When I speak without the megaphone, waves spread in all directions from my mouth. With the megaphone, instead of sound waves flying off in all directions, they are spread over a smaller area or solid angle. So, for the same power, the intensity is greater.

(c) (8 pts) **(i)** I hold a big stone and stand on a boat. The boat is floating on a pond. If I drop the stone into the pond and the stone sinks, will the level of the pond rise, fall, or not change? Explain. **(ii)** If all icebergs (made of pure ice) floating on the sea melt due to global warming, will the sea level rise, fall, or not change? Explain. Note that the mass densities have the relation $\rho_{\text{sea}} > \rho_{\text{water}} > \rho_{\text{ice}}$.

(i) The level of the pond *falls*. When I hold the stone, the weight of water displaced by the stone is equal to the weight of the stone. In other words, the volume of the displaced water in this case is larger than the volume of the stone (note $\rho_{\text{stone}} > \rho_{\text{water}}$). Therefore, when I drop the stone into the pond, the level of the pond falls. **(ii)** The sea level *rises*. When icebergs float on the sea, the volume of the displaced sea water is $\Delta V_1 = m_{\text{iceberg}}/\rho_{\text{sea}}$; After icebergs melt, their mass does not change and the volume that the water occupies is $\Delta V_2 = m_{\text{iceberg}}/\rho_{\text{water}}$. Because $\rho_{\text{sea}} > \rho_{\text{water}}$, we have $\Delta V_1 < \Delta V_2$.

(d) (8 pts) Two blocks of mass M are stacked one on top of the other, with the lower block attached to a horizontal spring with spring constant k (on a frictionless surface). The two masses are put into oscillation with amplitude A (about $x = 0$), which is low enough such that the two masses do not slip relative to one another. If the top block is removed at the instant the masses reach $x = 0$, what happens to the oscillation (comment on changes to frequency and amplitude). Explain.

The frequency changes (increases) because I reduce the total mass in the oscillator. The amplitude changes because I remove energy if I remove the mass at x=0. At this point ALL of the energy in the motion is in kinetic energy. Since this energy depends on mass, if I remove mass from the system, I take energy with it. This means that the amplitude of the oscillation has to decrease.

[2.] (32 pts) A spring of unknown spring constant is hung from the ceiling; a block of mass m is attached to the bottom of the spring (gravity acts downward, you can assume the acceleration due to gravity is g). I find the mass and spring hanging in equilibrium. I now attach a second block of mass m to the first and then release the two blocks. I see that the two blocks fall a distance h before stopping momentarily.

(a) What is the amplitude of the resulting oscillation?

(b) What is the frequency of the resulting oscillation? (Note that you don't know the spring constant k (but you can figure out what it must be). You must write this answer in terms of the given quantities).

(a) The amplitude is $h/2$. We know the mass stops after dropping distance h. The mass starts with gravitational potential energy, after dropping distance h, the energy is all stored in the spring. The mass will oscillate back and forth between these states, moving a total distance h during the oscillation. The amplitude of an oscillation is half the total distance traveled – during the oscillation the mass goes from +A to -A, covering distance 2A.
(b) We just need to find k here. After adding the additional mass, we know that the new equilibrium position is $h/2$ below the old equilibrium location. Before adding the additional mass, the system was in equilibrium with the spring force balancing the force of gravity. In this situation, the spring is stretched a distance y_1 so that $mg = ky_1$. After adding the additional mass, we can call the new equilibrium location y_2 (this distance is relative to the *unstretched* length of the spring). We know that $2mg = ky_2$. The difference between y_1 and y_2 is $y_2 - y_1 = h/2$. So we can subtract the two previous equations to get:

$$mg = k\frac{h}{2}$$

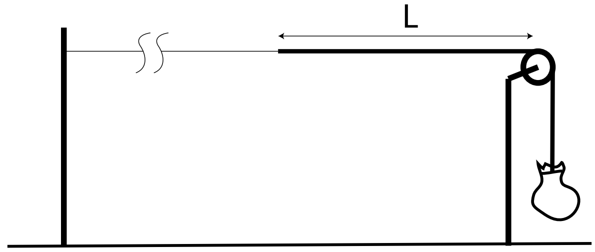
or

$$k = \frac{2mg}{h}$$

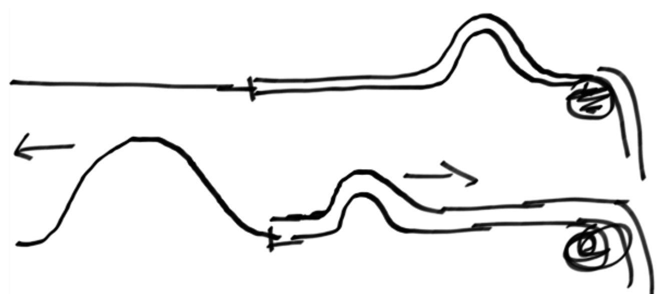
The frequency of oscillation is therefore:

$$\omega = \sqrt{\frac{k}{2m}} = \sqrt{\frac{g}{h}}$$

[3.] (32 pts) A composite string is made up of a short length of heavy string (μ_1) and a very very long length of much lighter string ($\mu_2 \ll \mu_1$). The light end of the string is attached to a pole very far away. The string is held under tension by passing the heavy end over a pulley and attaching it to a bag full of sand. The heavy segment of the string has length L (between the pulley and the knot between the two strings).

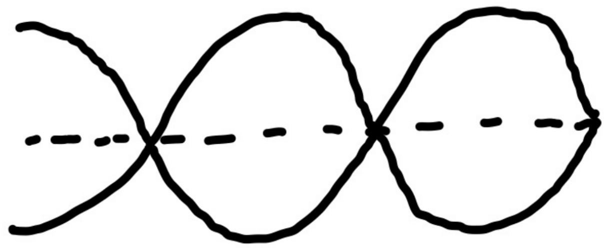


(a) I pluck the end of the string by the pulley, launching an upright pulse that travels to the left starting on the heavy string. When the pulse encounters the knot between the light and heavy string, I see a transmitted and reflected pulse. Draw the reflected and transmitted pulses, clearly indicating any differences in: spatial size, amplitude, and polarization (upright or inverted).



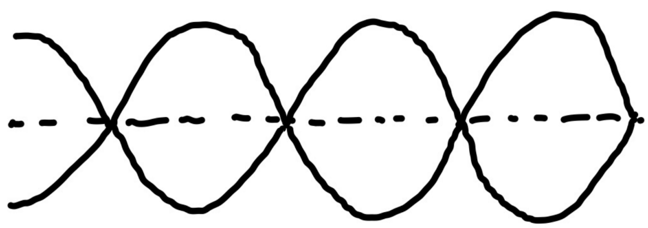
The reflected pulse is upright, has the same spatial size/width, and has a smaller amplitude than the incident wave. The transmitted pulse has larger amplitude and is stretched out (larger spatial width) compared to the incident wave.

(b) I now excite the string sinusoidally in time by gently shaking the pulley up and down; the frequency I excite the string at is variable. I start at a very low frequency and slowly turn up the frequency. As I do this, I see standing waves appear on the heavy portion of the rope. I turn the frequency up until I have found the third such standing wave. Draw the pattern that this standing wave makes on the heavy rope.



The knot between the heavy and light rope acts as if it is a free-end boundary condition for waves propagating from the heavy rope into the light rope. So it looks like a string with one fixed end (at the pulley) and one free end. The third standing wave is the 5th harmonic, which has 5/4 wavelengths fitting on the string.

(c) I now leave the frequency of excitation fixed (the third standing wave is being excited) and then I cut a small hole in the bottom of the sand bag so that sand starts slowly trickling out, lowering the mass of the sand bag. At first, my exciting frequency goes out of resonance, and I do not see a standing wave on the heavy part of the string. After a short while later however, I see a new standing wave excited on the string. Draw this standing wave.



As the mass of the sand bag decreases, so does the tension in the rope. This lowers the wave speed on the rope and therefore decreases the wavelength associated with a fixed frequency. So the standing wave that shows up next should have shorter wavelength, and this will be the next higher harmonic of the string, the 7th harmonic, with 7/4 wavelengths fitting on the string.

(d) What is the fractional change in the mass of the sandbag at that instant ($m_{\text{new}}/m_{\text{old}}$)

The frequency of excitation is the same in both cases, but the wave speed and the harmonic numbers are different. Before I poke a hole in the sand bag, the frequency must equal:

$$f = \frac{5v_1}{4L} = \frac{5}{4L}\sqrt{\frac{m_{\text{old}}g}{\mu_1}}$$

After some mass has drained out of the bag, the frequency must equal:

$$f = \frac{7v_2}{4L} = \frac{7}{4L}\sqrt{\frac{m_{\text{new}}g}{\mu_1}}$$

I can set these two expressions for f equal and solve for $m_{\text{new}}/m_{\text{old}}$:

$$\frac{m_{\text{new}}}{m_{\text{old}}} = \frac{25}{49}$$