Notes on Sonoluminescence

1. Here are some rules that **you must abide by**:
   a) **The plastic tank**: This tank is made flimsy on purpose! The walls must be "soft" so a pressure node occurs at all boundaries of the tank. When filling or emptying the tank, grab the 1/2"-diameter threaded rod to tilt the wooden box upon which the tank is mounted. When you do the tilting, make sure that the ultrasonic horn is not attached to the rod.

   b) **The "boiler"**: When this heated wire is not immersed in water, make sure that its phone jack is disconnected from the main electronics box. This way, if the electronics is on, an accidental pressing of the boiler pushbutton will not result in the wire melting!

   c) **The photomultiplier tube (PMT)**: Before working with the PMT, always make sure that its Gain knob is set fully counterclockwise and its LED pilot light is off. If the normal high voltage is applied to the PMT, exposure of its photocathode to room light will destroy it—a $700 mistake! There are two ways to make sure the photocathode is covered: (1) The PMT base can be twisted relative to the black-tape-covered shield so that the two white lines on the base are aligned with the two white lines on shield labeled "C" (for "Closed"). (2) The rubber cork with the green LED inside can be inserted into the larger rubber cork that has an opening to the photocathode. To expose the PMT, twist the base until its white lines are aligned with those on the shield labeled "O" (for "Open"). To observe the response of the PMT to light, insert the LED into place and then twist the shield so the photocathode can "see" the LED. Note that the current to this LED should not exceed ~ 1 μA. Later on you will connect the PMT to a microscope in order to observe the flashing associated with sonoluminescence. First make sure that the PMT is turned off. Now you can twist the base so the photocathode is exposed, but try to avoid exposing the photocathode to bright lights. Next insert the PMT into the eyepiece region of the microscope. Also make sure, before turning the PMT on, that no room light is in the field of view of the microscope due to leaks through the black-cloth shrouds. A black piece of paper on the opposite side of the tank from the microscope might help.

2. 1st Experiment: Use degassed water that is at room temperature. This way the water's temperature will not vary much as you perform your experiments. Carefully fill the tank to the 10-cm level, dip the end of the horn about 5mm into the water and **carefully** connect the blue coaxial cable to the horn. Dip the thermometer briefly into the tank and record the temperature. Is the temperature uniform throughout the tank? Set the oscillator frequency to about 27 kHz and the amplitude to ~ 2 V as seen on the meter. See if you can find a resonance slightly below this frequency. As you approach the resonance condition, you will probably need to reduce the horn drive to keep the response ~ 2. Set up the oscilloscope to look at the normal and high-frequency outputs and trigger the 'scope on the normal output. You can also program the oscilloscope so it displays

on its screen the amplitude of the normal output. At resonance adjust the drive so the 'scope reads 1-V amplitude. Now vary the frequency and plot out the 'shape' of the resonance curve. The easiest way to estimate the Q is the note the frequencies at which the output has dropped to $1/\sqrt{2}$ of the maximum at resonance.

At resonance, connect thin-rod detector output to a third channel on the 'scope, insert the rod into the water, and find the vertical positions of the antinodes along the middle of the tank. Note the phase change in this signal as you move between adjacent antinodes. A mirror is provided to help eliminate parallax problems. You might also explore the signal at other locations in the tank. See if the distances between the antinodes agree with expectations.

After removing the thin-rod detector, you might also want to explore higher frequencies where there may exist other resonances with different output signals. Usually the water remains degassed for only about 2 hours. The degassed state is supposed to be important for seeing sonoluminescence, but we are not sure that such degassing is important at room temperature at the low sonic drive levels that you are using. Help us answer this question.

Eventually you will want to use the microscope to look at the sonoluminescence of a trapped bubble. Since the microscope has a rather narrow field of view, it is difficult to align the microscope with the three antinodes; and the rough antinode positions determined with the thin-rod detector are not accurate enough. To do a better alignment, replace your room-temperature degassed water with "gassy" water straight from the while tap. With the diverging lens (f = -25mm) in front of the HeNe laser, turn on the sound and shine the broadened laser beam at the expected position of the lowest antinode. Because there are lots of air bubbles in this water that will be attracted to the antinodes, you should see a multi-bubble structure trapped at this lowest antinode, as illuminated by the laser beam. Pulse the boiler and see what happens. Some students have had fun making a movie of the bubbles being attracted to this antinode. Now align the microscope so this visible antinode is at the center of the cross hairs and make some alignment marks on the fine-adjustment vertical positioner to the left of the microscope. Repeat the procedure for the other two antinodes. You may need to raise the boiler to get better bubbles at these higher antinodes. These alignment marks will give you a more accurate measure of the vertical separation between the antinodes that you can compare with expectations. So far no students have tried to do this experiment with cold "gassy" water. Since the antinode positions might be different at lower temperatures (also different resonant frequencies), it would be interesting to find out whether the cold and warm antinode positions are the same.

Given the sound velocity, in principle you can calculate the expected resonant frequency for the (1,1,3) resonance. Because the plastic box is "floppy," it is not clear what horizontal dimensions should be used—inside or outside? So we provide both average dimensions: Inside: 5.40 ± 0.03 cm; outside: 5.76 ± 0.03 cm. Note that the error bars reflect the fact these horizontal dimensions are about 0.06 cm larger at the top of the water in comparison those dimensions at the

bottom of the tank. Also compute the expected positions of the antinodes and compare with your results from the previous paragraph.

3. 2nd Experiment: Now you can try refrigerated degassed water that usually has an initial temperature of ~5 °C. Your best resonance at these lower temperatures will occur below 27 kHz. Initially keep the drive level low enough so the detector output is ~ 2V. Unfortunately as the water warms the resonant frequency will keep increasing. Why? So to measure Q, you need to quickly shift the frequency to the two $1/\sqrt{2}$ points on either side of the resonance peak. At resonance you could see if the positions of the antinodes are similar to what you obtained with the water at room temperature. Now increase the horn drive until the voltage on the meter is ~ 8 V at resonance. Insert the 'boiler' wire into the tank and put the wire near the bottom the tank. Pulse the boiler and watch the 'scope output, as outlined in the manual. If you obtain the signature of a stable bubble, drop the black curtains and see if you can see the sonoluminescence of a bubble trapped near the bottom of the tank. It will take several minutes for you to become dark adapted, and it might work better for your partner to monitor the 'scope to make sure that a bubble is trapped. Does the light come from the location that you expected? You can raise the 'boiler' and see if you can trap another bubble at the next antinode.

4. 3rd Experiment: You may want to replace the now warm water with some more degassed cold water. Now put the horn into position and trap a bubble. See if you can see the sonoluminescence through the microscope.

5. 4th Experiment: Measuring the timing of the sonoluminescence flash and its intensity with the PMT. Flashes from adjacent antinodes should be 180° out of phase—show this! This is a complex experiment. We will discuss the details with you. As indicated in Sec. 1(a), we have provided a green LED that you can shine onto the PMT so you can observe the PMT's output characteristics. Eventually you will insert the PMT into the eye-piece part of the aligned microscope. The intensity of the sonoluminescence output is supposed to drop as the temperature rises.

6. 5th Experiment: It would be nice to observe the actual size of the bubble and correlate the change in bubble size with the sonoluminescence flash. To do this, one shines a 4mW HeNe laser beam at the bubble and collects the scattering laser light with the microscope and the PMT. A bigger the bubble scatters more light. Also, using the HeNe laser beam, you can try to estimate the maximum size of the illuminated bubble relative to the width of the cross hairs of the microscope. Then you can image a fine wire of known diameter to calibrate the cross hairs, but be sure to put the fine wire into the **water-filled** tank.

7. 6th Experiment : You could try to dose rare gas into the water and see how the sonoluminescence characteristics change with different dopants.