Sonoluminescence Experiments

Sonoluminescence is the process where a small gas bubble is both trapped and oscillated by an acoustical field. During the collapse of the bubble on each cycle a brief pulse of light is emitted. You will measure the effect of the drive amplitude on this light output as well as some of the temporal properties of the light itsself.

To get started first prepare the water see that you can obtain a stable glowing bubble as outlined in the instructions. This may take some time to aquaint yourself with the system. Once you are comfortable that you can find the resonance of your cell and generate a bubble you are ready to begin.

The first aspect of SL that you will investigate is an understanding of the basic acoustics of the rectangular cell being used. Once you have mastered this you will want to investigate the range of driving amplitudes on the light emission. You will measure the high frequency response of the pill as well as the light output of the system both as a function of drive amplitude.

Exploring the Acoustics of the (1,1,3) Mode

In order for a bubble to be trapped by the acoustic field the bubble must sit at a pressure antinode. The frequencies at which this will occur are dictated by the size and shape of the cavity. In this case we are using a rectangular cell with the X and Y dimensions equal. Starting from the basic acoustic wave equation we have

$$\nabla^2 P = \frac{1}{c^2}\frac{\partial^2 P}{\partial t^2}$$

where the acoustic pressure variation is given by

$$\delta P = \delta P_o X(x) Y(y) Z(z) T(t)$$

and where the time dependence varies harmonically as

$$T(t) = \mathrm{e}^{\imath\omega t}$$

Expressing ∇^2 in rectangular coordinates

$$\frac{1}{X}\frac{\partial^2 X}{\partial x^2} + \frac{1}{Y}\frac{\partial^2 Y}{\partial y^2} + \frac{1}{Z}\frac{\partial^2 Z}{\partial z^2} + \frac{\omega^2}{c^2} = 0$$

A general solution of this equation is of the form

$$P \sim \sin(k_x x)\sin(k_y y)\sin(k_z z).$$

In order to satisfy the boundary conditions at the cell walls we impose restrictions on the values of k_x, k_y, and, k_z such that $k_x = n_x\pi/L_x$, $k_y = n_y\pi/L_y$, and $k_z = n_z\pi/L_z$ where $n_{x,y,z} = 1, 2, 3...$ Although $n = 0$ is allowed this will not generate a pressure gradient and is thus discarded.

The resonant frequencies for trapping are then given by the expression

$$f_{n_x,n_y,n_z} = \frac{c}{2\pi}\sqrt{\left(\frac{n_x\pi}{L_x}\right)^2 + \left(\frac{n_y\pi}{L_y}\right)^2 + \left(\frac{n_z\pi}{L_z}\right)^2}$$

where $L_x = L_y = 5.2$cm and $L_z = 10.0$cm are the dimensions of the cell and $c = 1.5 \times 10^5$cm/s is the speed of sound in water. Putting in the values of 1 for n_x and n_y and 3 for n_z implies that the resonance frequency will be close to 28 kHz and that there will be three pressure antinodes in the Z direction and one pressure antinode in the X and Y direction. Further examination of the soultion will reveal that the second pressure antinode located at the center of the cell will be 180^o out of phase with the first and third antinodes (located near the bottom and top of the cell respectively.)

Try to light up all three antinodes at once by first holding the boiler filament near the bottom and seeding a bubble near the bottom. When this is done place the filament near the middle and seed another bubble near the middle and finally seed one near the top. The bubbles will generally migrate to the closest pressure antinode. Once all three bubbles are going you may verify with a PMT and an oscilloscope that the one in the middle is out of phase with the ones at the top and bottom. You can of course solve the above equations to find other modes some of which will be degenerate and try and trap in those as well.

Determining the quality factor of the resonance curve

The rectangular cell used with the SL100 system is able to build up sufficient pressure amplitude to trap the bubble through resonance enhancement of the pressure amplitude. We can crudely think of the dynamics of the acoustic pressure as a 3 dimensional extension of driven damped harmonic oscillator. In the case of a driven damped harmonic oscillator x can be expressed as

$$x = \frac{X_o e^{i\omega t}}{Z_m}$$

where

$$Z_m = \sqrt{R_m^2 + (\omega m - s/\omega)^2}$$

In this case m is the mass, s is the fornce constant and, R_m is the damping term. The sharpness of the resonance is denoted by the quality factor Q which is defined as

$$Q = \frac{\omega_o}{\omega_2 - \omega_1}$$

where ω_1 and ω_2 are the frequencies below and above the resonance frequency at which the average power is one half that at resonance. The rectangular cell used in this system has a $Q \sim 200$. Since the power is proportional to the pressure squared the frequencies ω_1 and ω_2 will occur when the pressure is $1/\sqrt{2}$ of the peak pressure amplitude.

Figure 1 shows a computed resonance response for a system that has a $Q = 200$ and a resonance frequency of 28 kHz. Determine the quality factor of your cell by first finding the resonance and noting the voltage that appears on the pannel. Adjust the frequency in 10 Hz increments both above and below the resonance frequency recording the value on the pannel at each frequency. Graph these values on a linear plot and confirm that your plot is similar to that of Fig:(1).

Another phenomena associated with acoustic systems is that of adiabatic invariance. Stated simply a system is said to be adiabatically invariant if a small pertubation in its shape which preserves the total volume does not shift the resonance frequency of the system (at least to first order). Try placing several small objects of varying density in the cell which will perturb the rectangular shape but keep the volume of water constant. See to what extent the resonance frequency changes.

Drive threshold of SL and high frequency response of pill

1. First setup the SL so that the bubble is stable and shinning. The output of the pill is routed through a buffer amplifier and then to the scope.

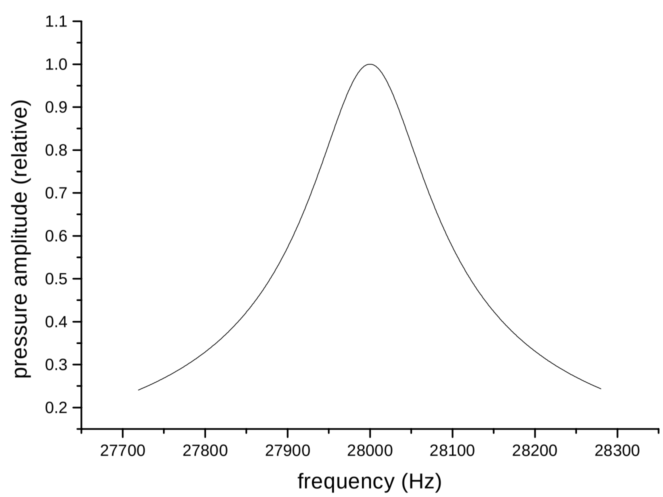

Figure 1: Pressure amplitude response of a driven system with a quality factor of 200.

2. Using a BNC T split the signal from the scope into 2 additional filters. Set one filter to have a low pass cut off frequency f_{c1} at 80-100 KHz using at least a second order filter. The second filter should be a high pass filter with a roll off frequency f_{c1} of about 100 KHz employing at least a fourth order roll off i.e 24 dB per octave. To the output of each of these filters connect a rms-to-dc converter (a high quality ac voltmeter will work).

3. The objective of this part of the experiment is to correlate the amplitude of the high frequency signarture with the drive amplitude of the bubble at resonance.

4. While maintaining resonance lower the drive amplitude to the point where the bubble is just visible. This is the lower threshold and is your starting point. Recored in tabular form the amplitude of the fundamental from the optput of the low pass filter and the high frequency signature from the output of the high pass filter.

5. Slowly increase the drive amplitude in small steps and recored the output of the two filters as before. Repeat this until you have reached a drive amplitude where the bubble is no longer stable and dissapears (this is the upper threshold). You should notice that the bubble gets progressively brighter at each level until it dissapears.

Correlating the light output and the acoustic drive

In this phase of the investigation we will look at the light output of the cell with a photomultiplier tube (PMT). A PMT is a very special instrument used to measure small amounts of light and convert this into an electrical pulse that can be measured on an oscilloscope or other device. When using a PMT you must exercise caution as extremely high voltages are used and excessive light into a PMT such as a room light will destroy it.

1. With the SL apparatus working connect the pill output to the lowpass filter and rms-to-dc converter as before. Place the PMT as close as possible to the face of the cell and connect the high voltage cable to the high voltage connector on the PMT and the high voltage power supply. DO NOT turn on the high voltage yet. Connect a BNC cable

between to the anode of the PMT and and a high speed oscilloscope. In order to prevent a high voltage buildup in the cable as it is transfered from one device to another use an inline 50 ohm thermination or a BNC T with a 50 ohm termination. This ensures that the anode output of the PMT always has a load into which it can drain and thus prevent a high voltage from appearing across a sensitive device.

2. If the measuring device you are using has an internal 50 ohm impedance you may omit the termination but you should connect the cable in the following manner. When connecting the cable to a device with a 50 ohm termination make sure the high voltage power is off. Then connect a short or a 50 ohm termination to the cable and remove it (this removes any static charge in the line). Now you may connect the cable and after the connection is made you may power up. before disconnecting a cable from a device that has an internal 50 ohm termination power down the high voltage and do not disconnect until the high voltage meter reads 0.

3. If you are measuring the PMT output with an oscilloscope set the scope to a frequency where you may observe the fundamental frequency of the pill in channel A and the PMT output in channel B. With the lights off slowly power up the PMT. You should see a series of negative spikes on the scope. Verify that you have one and exactly one spike each acoustic cycle.

4. Now change the time base and triggering of the scope so that it is triggering on the negative pulse from the PMT. Lower the amplitude to the lower threshold and record the output of the low pass filter as well as the amplitude of the PMT pulse on the scope.

5. Slowly incrase the drive amplitude and record the output of the low pass filter and the amplitude of the PMT. Repeat this as before until the upper threshold is reached.

Measuring the time duration of an SL flash

1. In this part of the experiment you will set an upper limit on the time duration of the SL pulse from a knowledge of your PMT's response time and the oscilloscope response time.

2. Consult the owners manual of you oscilloscope and find the maximum bandwidth in MHz. A useful rule of thumb to remember is that bandwidth (in GHz) is equal to the quotient of 0.35 and the rise time (in nanoseconds)

$$BW = 0.35/\tau_r.$$

   From this calculate the effective rise time of the oscilloscope τ_{scope}. The risetime τ_r of a signal is defined as the time it takes the signal to transverse from 10% to 90 % of its final value.

3. The rise time on a PMT is usually deterimined experimentally by looking at its response to a very fast impulse (usually several hundred femtoseconds). Most PMT's have a rise time from 100 ps to 2-4 ns. Find out from the manufacturer what the effective rise time of your PMT is and record this value as τ_{PMT}.

4. To keep the units the same convert all the risetimes to picoseconds and find the overall effective risetime of the system from the following formula

$$\tau_{sys} = \sqrt{\tau_1^2 + \tau_2^2 + ...} = \sqrt{\tau_{PMT}^2 + \tau_{scope}^2 + \tau_{SL}^2}$$

   Note that the risetimes add in quadrature and that the total risetime of the overall system will be greater than the largest risetime of any of the components. Stated another way the overall bandwidth of the system will be less than the component with the lowest bandwidth.

5. With the SL running measure the risetime of the oscilloscope's output and verify that the meassured risetime is essentially comprised of the risetime of the scope and the PMT.

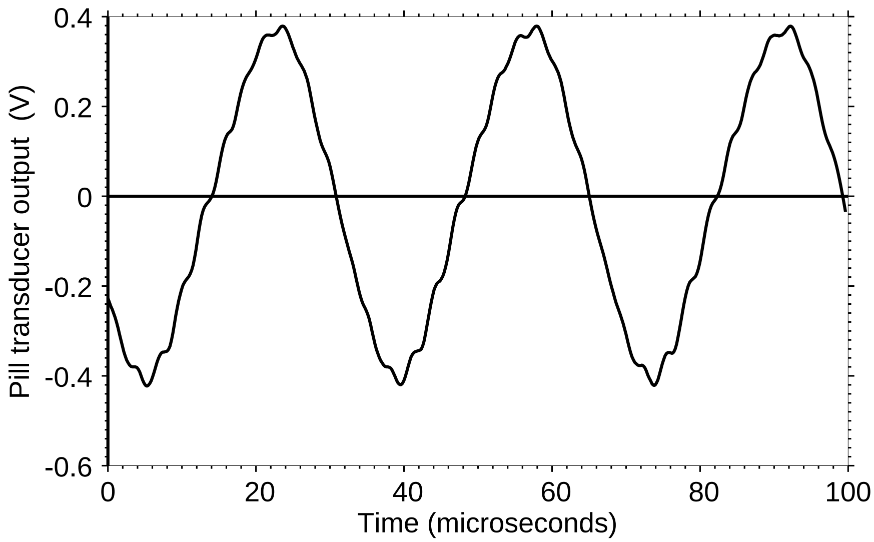

Figure 2: Distortion that appears on scope when SL is established. Note the relative magnitude of the distortion to the sine wave response of the pill