Experiment 3: Shooting a laser at a bubble and Sonoluminescence

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Dated: May 30^{th}, 2019

I. INTRODUCTION

In this experiment we sought to observe the effect of sonoluminescence that occurs in a bubble trapped in a sealed water chamber. There is no consensus on what causes sonoluminescence to occur, though the properties of sonoluminescence is such that bubbles in there dynamics are become a black body as well as emit light in visible frequencies. The overall study of sonoluminescence began in the 1930's, at that time, the effect was just a property seen in materials where caviation occurred, it was later discovered that the bubbles themselves were the proprietor of the sonoluminescence effect. Eventually the scholars of the effect were able to breakdown the experiment into simpler models from a multi-bubble solution to then a single bubble, even then the parameters and equations charting the bubbles are also taken into consideration, where the temperature, volume, pressure, and solution are taken into account and understood how they interfere with the bubble. Though the most important factor in creating these bubbles is the frequency of the sound waves moving through the medium which allows for the formation of bubbles and the radius of the bubble when first emitted, afterwards the observations that could be made was only the light emitted by the bubble and the reflected laser from the bubble.

II. THEORY

A theory that shows why light beams are emitted for sonoluminescence, is that the bubbles in a trapped chamber undergo rapid decay in size as the sound wave moving through the chamber the bubble is trapped in goes from an anti-node to a node, this causes a shift in pressure and a shift in the bubble size, it collapses rapidly, so much that its release of excess energy reveals light. There are many factors that contribute to a bubbles formation and the release of light. These factors include the waves temperature, volume, pressure, solution, and acoustics in the chamber where bubbles are being trapped. Though there is much mathematical theoretical analysis on the dynamics and properties associated with the bubble from various factors they are not important to our analysis since we sought to observe the bubble itself after it was formed and not associate with more complex material as it was unnecessary for the results we were seeking was the period, width, and amplitude of the sonoluminescence which can be gathered using a photo multiplier, as well as shining the laser with the photo-multiplier.

We study the dynamics of the bubble by using a laser beam and observing the event on a computer reading a photomultiplier. The scattering we observe is classified as mie scattering. The first piece of data we note is that the intensity of the scattering is proportional to the square of the bubble radius allowing us to measure the radius of the bubble through time.

In this observation of the bubbles radius go up and down, we observe positive acoustic pressure decrease the bubbles radius and the negative increase it. When the bubble begins to shift from increasing to decreasing in size it causes after bounces.

We observe that the acoustic drive amplitude increasing makes bubbles emit light basically being to control sonoluminescence, we also see that the collapse point in each acoustic cycle releases a pulse of $10^6 - 10^7$ photons released in 100 ps.

At minimum radius gas in the bubble can be heated to 17,000 K enough to ionize and form plasma of the gas, we analyze this incident by comparing the theoretical plank black body given by equation 1.

$$L(\lambda, T) = \frac{c_1}{\lambda^5(e^{c_2/\lambda t} - 1)} \qquad [1]$$

λ is the wavelength, T is the temperature $c_1{=}1.19*10^8(W/m^2),c_2{=}1.439*10^4(Kum)$. This describes the Plank Black body correlation to emitted light and can give us the temperature spectrum for the bubbles emitted light.

III. APPARATUS AND PROCEDURE

The equipment we needed to accomplish our experiment went as followed. To generate and trap bubbles we had to use a sophisticated chamber, with two Piezoelectric drivers at both end caps, the walls of the chamber are pyrex glass, there is a heater filament at the bottom of the box that jumps to a voltage tuned outside the chamber. We also have a PVDF microphone on stainless steel on part of the outside of the chamber to drive acoustical waves in the chamber, lastly we have fill lines with copper covers to allow for degassing of the water. We show the apparatus in figure 1.

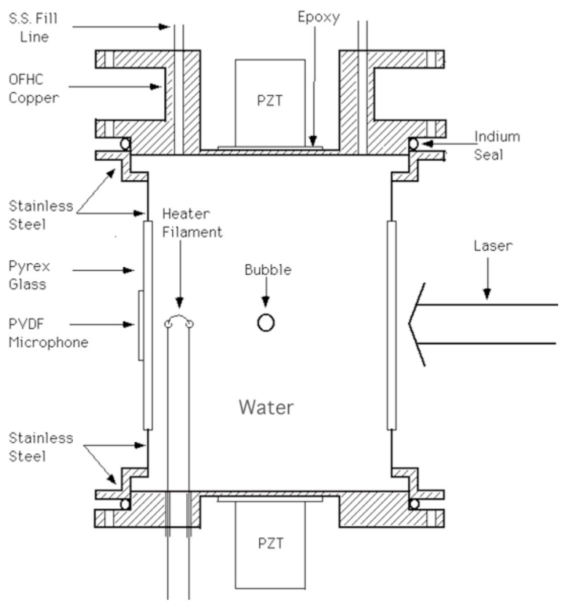

Figure 1: This Diagram shows the acoustical resonator driven by a PZT at both end cap, a bubble is injected with a wire heated with a variable voltage supply.

The next device we used was a laser, this was a 10mW laser, powerful enough to cause damage so precaution was taken and we shoot at a piece of glass to cause a more diffraction time.

The last major device we used was a photomultiplier, which is a device able to capture photons and multiply to small amount of light using electrons as substitutes.

We used two filters one blocking all wavelengths below 520 nm and another blocking all wavelengths above 520 nm.

In this experiment we wanted to measure the bubbles size throughout the its lifespan as well as the light emitted by it. To start we had to trap a bubble in our enclosure. So we tuned our resonator to a mode near 32 kHz and trap a bubble by flickering heater current. We then adjust the acoustic amplitude to a value larger than minimum needed to trap the bubble.

We then start shining the laser on the bubble and witness the mie scattering with the photomultiplier, and this also allows us to measure the radius of the bubble. We turn on averaging on our oscilloscope on 1024 pulses and this gives us an accurate measurement of the bubble.

Then we increase the drive amplitude to see ant difference in bubble dynamics, and see if any sharp spikes at minimum radius of the bubble which is the sonoluminescence. We then fine the upper threshold till bubble trapping is lost.

Then we had to re-trap the Sonoluminating bubble and turn off the laser to measure the width of the SL pulses and verify they are consistent with the period of the drive amplitude. WE expand the time of the oscilloscope to a nanosecond time frame.

The last task we undertook was estimating the optical spectrum by using two filters in the photomultiplier. We compare the intensity of our spectrum's by integrating the spectrum from 250 nm to 800nm.

IV. DATA AND ANALYSIS

The first thing we did was trap the bubble we accomplished this at the frequency of about 32100 Hz to 31900 Hz, specifically 31990 Hz at many points. We also were able to adjust the voltage from 1.16 to 1.92 volts.

The next thing we had to do was take two measurements of the Mie scattering and measure the radius vs time of the bubble which can be seen in figure 2 and 3. The first graph displays poor data but shows the oscillation clearly, for figure 3 we can see a gradual but pulsed decay and at its apex it spikes this is where sonoluminescence occurs again.

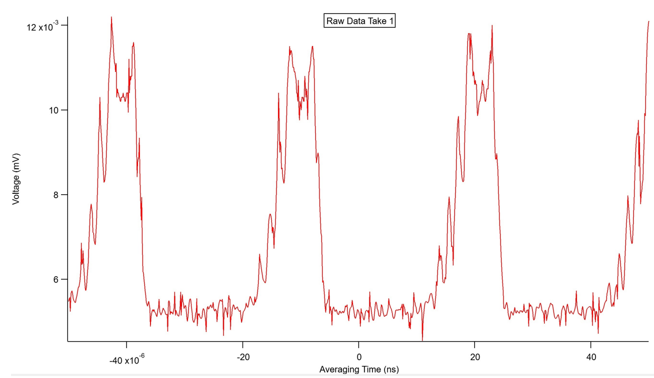

Figure 2: This is the Raw data of our first capture of the Mie scattering it displays poorly.

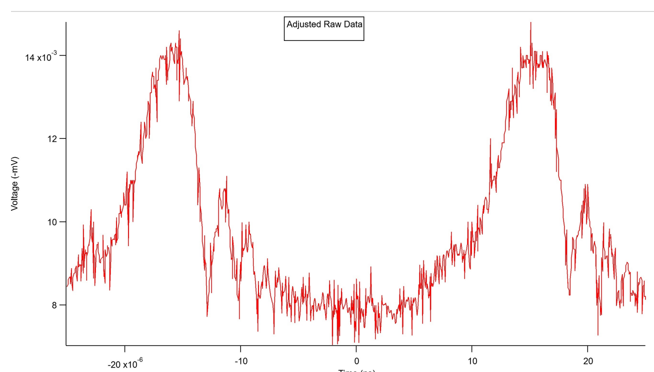

Figure 3: This is the refined capture of the Mie Scattering where you see clear steady rises and a spike at the peak and then a oscillating decay.

Then we had to take measurements of the Period which can be seen in figure 4. There is not much to say other than the period was about $30 \pm 2ns$ and width of the SL pulses which can be seen in figure 4. Afterwards we had to then take measurements of the width of the pulses that correlate to the light emitted by the bubble over a time frame of its period which can be seen in figure 5.

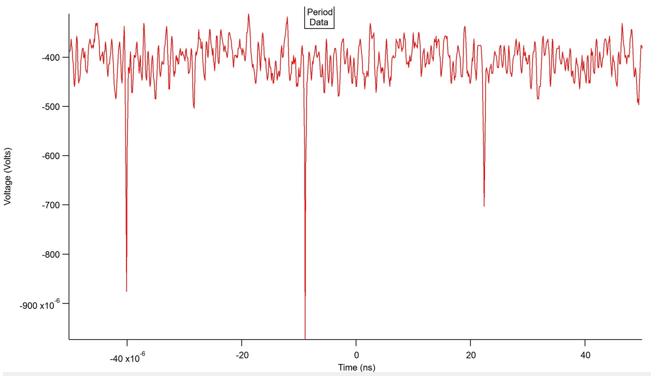

Figure 4: This Diagram shows the Period that the bubble expansion and decay go through with the spike being sonoluminescence point where decay beings again.

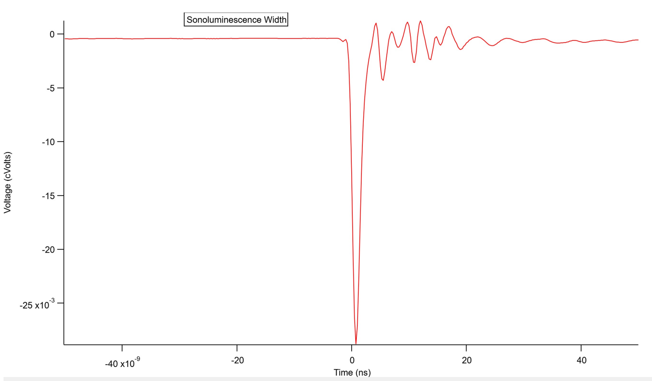

Figure 5: This graph is representative of the Sonoluminescence Width of pulses and the corresponding voltage peak points, for the bubble.

The next thing we had to do was get an estimate of the optical spectrum of the SL with filters. We show the filter spectrum's in figures 6 and 7. We also had to use these graphs to find the temperture, we show the results below.

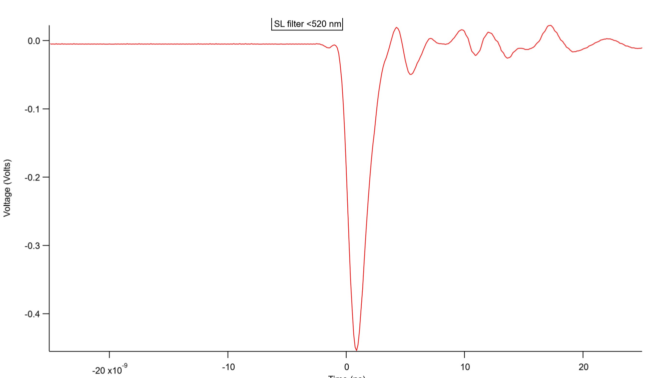

Figure 6: This is the SL width of the bubble with the addition of a <520nm Filter showing a voltage similar to a normal pulse.

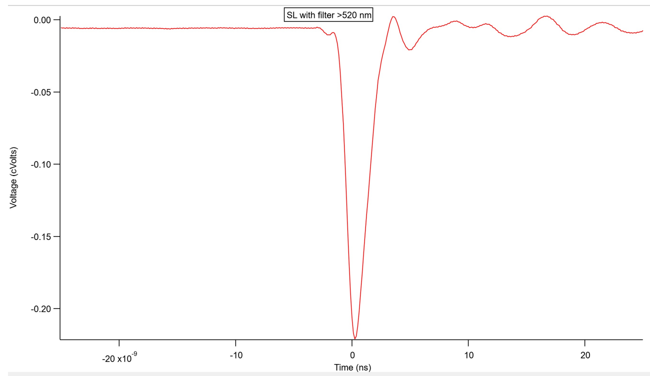

Figure 7: This is the SL width of the bubble with the addition of a >520nm Filter showing a much lower voltage than a normal pulse.

Lastly we had to compare the intensity ratios of the black bodies so we integrate equation 1 from the limits from 250 to 800 nm and then apply a temperature that will match a ratio of the two filters we observed. The comparison of the intensity of the two filters, the $> 520nm$ filter had a max of 220 mVolts and the $< 520nm$ filter had a max of 470 mVolts, from that we found a ratio of 2.14. Using equation 1 and figure 8, we found the temperature that would match the ratio from integration would be about 12500 Kelvin, this is off from the 17000 Kelvin we want but displays that the bubble is producing incredible energy and temperatures clearly.

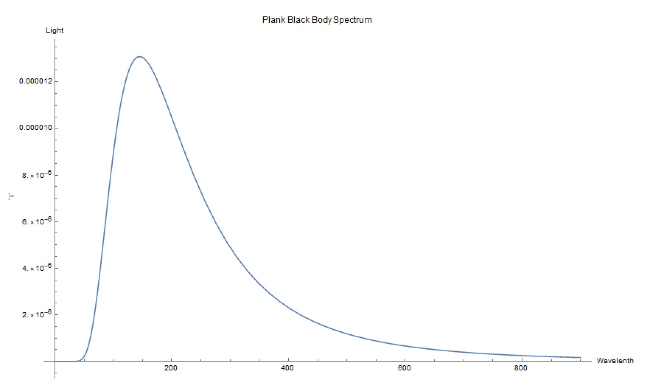

Figure 8: This figure shows the Planck Black Body Spectrum at 20 Kelvin, though a proper Temperature was used for the final calculation.

V. ERROR ANALYSIS

Since we did no calculations in the experiment but rather just observed the collection of raw data we did not have propagating error throughout the theory and data but rather the only error we encountered was experimental error. For this experiment the only experimental error that we were likely to encounter would come from the collection of the light data from the photomultiplier when capturing laser and Sonoluminescence. Though this would cause error in the collection of data we witnessed how the data transformed. Though other sources of error can mean that the data is shifted, off by percentages we cannot detect without further calculations, or just exhibiting behaviors that correlate but do not represent what is occurring physically. Though in this case outside light is diminished by making the room closed and all other sources off, as well as making sure the electronics and mechanical apparatuses were in top condition continuously throughout the experiment with even shifting and re-positioning all equipment for optimal capture of data, and lastly a thorough analysis of the data with multiple takes and making sure all outside effects minimized and any anomalies in the data categorized, such as the occurrence of Sonoluminescence in the laser data.

VI. CONCLUSION

In this experiment we were faced with many challenges though we moved past them all by careful analysis and checking our results thoroughly. In our experiment we sought to observe the generation, and life cycle, as well as Sonoluminescence for single bubbles, this meant we had to take into account all physical factors, which in this case, meant we had to make sure the water was degassed and that the heater in the water was working properly, we take into account the necessary voltage and frequency for the generation of bubbles, also we interacted with a laser and had to make sure everything was in proper orientation. In the end what we can conclude is that acoustical waves in a chamber can generate bubbles that then emit light and can heat gas to super high temperatures in points of its lifespan. While there is no consensus on why bubbles undergo such effects they naturally form these patterns and habits and thus can be exploited. The data we observed followed theory and sources of error can come from the fact no system is perfect and outside light may effect but not heavily impact our data. In the end our results were highly accurate and provide a thorough analysis of what a the life cycle, emitted light, and size of the bubble were.