Version xx as of October 15, 2018
Primary authors: Nathaniel Lawson, Kevin Coxon, and Steve Kim
To be submitted to RSI

Apparatus for Observation of Sonoluminescence

(Dated: October 15, 2018)

We attempt to observe sonoluminescence using acoustic bubble traps. We us a mixture of different methods to trap bubbles of two different gasses in standing waves of sound in two different types of water. Although we are able to trap bubbles twice using one of the methods and combinations, we fail to detect emissions of light from our bubbles.

PACS numbers: 43.35.HI

I. INTRODUCTION

Sonoluminescence is the process where a small gas bubble is trapped by an acoustic standing wave in a fluid in such a way that the bubble expands and the contracts violently in time with the wave, emitting light as it contracts. The exact nature of the process is not well understood.

A bubble must sit at a pressure antinode to be trapped by the acoustic field. The acoustic wave equation is

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

Which in 3D rectangular coordinates equals

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

The time dependence of the wave is

$$T(t) = e^{i\omega t} \tag{3}$$

and the variation of the acoustic pressure is

$$\delta P = \delta P_0 X(x) Y(y) Z(z). \tag{4}$$

The general solution for the pressure wave is

$$P \approx sin(k_x x) sin(k_y y) sin(k_z z), \tag{5}$$

Where $k_x = \frac{n_x \pi}{L_x}$, $k_y = \frac{n_y \pi}{L_y}$, and $k_z = \frac{n_z \pi}{L_z}$, with n_x, n_y, and n_z equalling 1,2,3... The n = 0 values do not produce a pressure gradient.

The resulting resonance frequencies are thus

$$f_{n_x,n_y,n_z} = \frac{c}{2\pi}\sqrt{(\frac{n_x\pi}{L_x})^2 + (\frac{n_x\pi}{L_x})^2 + (\frac{n_x\pi}{L_x})^2}, \tag{6}$$

Where L_x, L_y, and L_z are the dimensions of the flask containing the standing wave and $c = 1481$ m/s [1], the speed of sound in water.

We can approximate the dynamics of the acoustic pressure on the bubble as a driving damped harmonic oscillator, where

$$x = \frac{X_0 e^{i\omega t}}{Z_m}, \tag{7}$$

where

$$Z_m = \sqrt{R_m^2 + (\omega m - s/\omega)^2}. \tag{8}$$

The mass is m, the force constant is s, and the damping constant is R_m.

A more accurate representation of the motion of the bubble is the Rayleigh-Plessett Equation [2]

$$\rho R\ddot{R}(1 - \frac{r\dot{R}}{c} - \frac{3}{2}\rho\dot{R}^2 = (p_0 + \frac{2\sigma}{R_0} - p_\nu)(\frac{R_0}{R})^{3\kappa} + p_\nu - \frac{2\sigma}{R} - p_0 - p(t) - \frac{4\eta}{R} \tag{9}$$

R is the bubble radius, η is the liquid viscosity, p(t) is the driving pressure, ρ is the liquid density, p_0 is the static pressure, p_ν is the vapor pressure, R_0 is the equilibrium radius, σ is the surface tension, and κ is the polytropic exponent. The density of water at $20°C$ is 0.9982 g/cm [3]. The viscosity of water at $20°C$ is 1.00160 mPa*s [4]. The surface tension of water at $20°C$ is 72.8 dynes/cm [5].

II. EXPERIMENTAL SETUP

A function generator produces the acoustic standing wave used in the experiment. It attaches to both an oscilloscope to measure to inputted wave and a device specifically designed for sonoluminescence experiments. The sonoluminescence device then connects to speakers attached to the sides of a flask by way of an inductor. The flask, which is suspended by a clamp, has a sensor on the bottom which is then connected to the oscilloscope to show the acoustic standing wave in the flask. Fig. 1 shows a sketch of this setup:

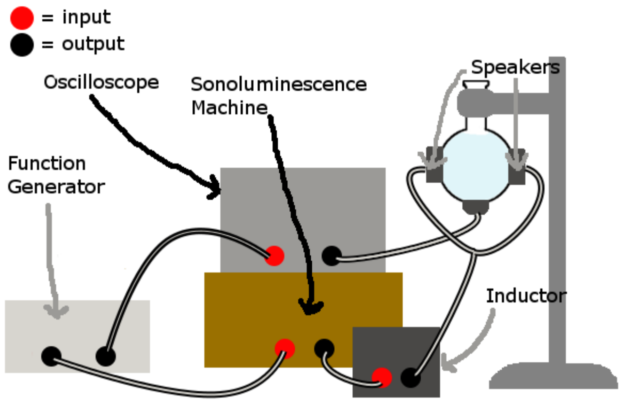

FIG. 1: A sketch of the apparatus.

III. PROCEDURE

We put water in a sealed container. For most of our trials, we use tap water, but we use reverse-osmosis water from Acros Organics during our last trial. We then degas the water in the container using a vacuum pump, keeping the container chilled in an ice bath. Once the water stops noticeably producing gas bubbles, we slowly open the container to the air and then transfer the water to the flask of our apparatus until the water level was slightly above the tops of the speakers. We primarily do this using a funnel, tilting the flask to reduce the production of air bubbles from the water splashing into the flask. However, during our last trial we instead use a syringe to exactly measure the amount of water placed into the flask to reach this level.

Once the water is transferred to the flask, we measure the resonance frequency of the sound waves emitted into the water-filled flask. We scroll across frequencies on the function generator, choosing the frequency that maximizes the amplitude of the standing wave in the oscilloscope. After finding this frequency, we adjust the driving voltage on the sonoluminescence machine to the point where the acoustic waves are just barely not audible. We then measure the amplitude of the resonance frequency wave on the oscilloscope. After finishing the measurements, we use two different methods of creating trapped bubbles in different trials. Our first method is filling a balloon with argon gas, twisting the end to trap the gas inside. We attach a pipette to the balloon lip and place the tip into the water. We then slowly untwist the balloon until bubbles begin exiting the pipette into the water, making sure that the bubble flow is gradual. We perform this method twice.

The second method is, using a syringe, sucking water from the flask and then squirting drops back in, producing bubbles from the splash. We perform this method three times. The first two times the bubbles produced are of normal air. However, in the final trial, we first fill the flask with argon until the air is displaced, causing the produced bubbles to be of argon.

During both methods, we turn out the lights after creating a few sets of bubbles and use a flashlight and colored lasers to check the flask for suspended bubbles trapped between the speakers. If we see trapped bubbles, we then shut off the flashlight and lasers to ascertain whether the bubbles are emitting any light, the signature of sonoluminescence.

If the flask does not contain trapped bubbles, we repeat the methods of producing bubbles until either trapped bubbles are observed or the water becomes too aerated to continue.

IV. ANALYSIS AND CONCLUSION

We begin by finding the frequency at which the amplitude of the speaker output wave was maximized in air. We record this resonance frequency in both the function generator producing the wave and the oscilloscope, in which the frequency experienced more variation. The function generator gives a resonance frequency of 28550.0000 ± 0.0001 Hz. The resonance frequency measured by the oscilloscope varies from 28.22 kHz to 28.91 kHz, although values outside the 28.35-28.75 kHz range are quite rare. This gives a resonance frequency of 28.57 ± 0.35 kHz, matching the function generator value quite well.

We also measure the magnitude of the peak-peak of the resonance wave (twice the amplitude), but find that the magnitude is not stable. Not only did the peak-peak value oscillate around a central value like the frequency did, but the central value varies with time, decreasing and then increasing over tens of minutes. The initial peak-peak measurement varies between 89.76 mV and 90.56 mV, but after 15 minutes the value is below 87 mV and 30 minutes after that, it has increased beyond its initial value. Ultimately, the number varies too much to judge the accuracy of the measured values.

We measure the resonance frequency in de-gassed water three separate times. The first time, the oscilloscope frequency ranges from 28.64-28.78 kHz, for a resonance frequency of 28.71 ± 0.07 kHz. The second time, the oscilloscope frequency is 28.75-28.99 kHz, for a resonance frequency of 28.87 ± 0.12 kHz. The third time, the resonance frequency is 28.70 ± 0.1 kHz. The second measurement differs from the other two, but all overlap within their margins of error. Again, the peak-peak value of the wave varies across time, preventing an accurate reading.

The first method for producing trapped bubbles is not very effective. During the first attempt, we observe something floating in the water, but it is not clear if it is a trapped bubble or contaminating particles, and we lose it before we could record what we see. The follow-up attempt completely fails at producing trapped bubbles.

The second method is far more effective at producing trapped bubbles. Both of the attempts with air record trapped bubbles. However, each fails to produce sonoluminescence. The third attempt of this method, involving reverse-osmosis water and argon gas, fails to produce trapped bubbles.

There were a number of sources of error in the trials that fail to trap bubbles. During the first two trials, which used the first method of creating bubbles, the bubbles that are produced are often larger than the optimal size for trapping. Furthermore, they generally come out in a stream rather than individually, which causes the bubbles to disrupt each other and increase the difficulty of trapping a bubble.

Before the final trial, the original container we use for degassing shattered, forcing us to replace it with a much larger container. The new container is far less effective at de-gassing the water, as the process produces far fewer and smaller bubbles during the de-gassing and finishes in a significantly shorter period of time. This is compounded by our decision to place the water in the flask by syringe in this trial in an attempt to measure the amount of water placed in the flask. The use of the syringe creates bubbles within the water, further contaminating the trial. These errors help explain the lack of ability to trap bubbles during the failed trials.

The failure to produce sonoluminescence during the trials where bubbles are successfully trapped can also be attributed to error. During every experiment, the de-gassed water has to be exposed to air before testing, both to transfer the water from the de-gassing container to the flask and to allow access to the flask for creating bubbles. This could contaminate the water. Furthermore, we are only able to successfully trap bubbles using air, while sonoluminescence has trouble occurring without noble gasses [6].

[1] Speed of Sound in Water:
Engineering ToolBox. Speed of Sound in Water. [online]. 2004. `https://www.engineeringtoolbox.com/sound-speed-water-d_598.html` [Accessed 09 Oct. 2018].

[2] Acoustic bubble traps:
Reinhard Gesiler, Thomas Kurz, and Werner Lauterborn, Journal of Acoustical Society of America **105**, 1078 (1999).

[3] Density of Water:
Ma, Allen. Density of Water. [online]. 2007. `https://hypertextbook.com/facts/2007/AllenMa.shtml` [Accessed 09 Oct. 2018]

[4] Dynamic Viscosity of Water:
Engineering ToolBox. Water - Dynamic and Kinematic Viscosity. [online]. 2004. `https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html` [Accessed 09 Oct. 2019].

[5] Surface Tension of Water:
Nave, Carl R. Surface Tension. [online]. 2017. `http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html` [Accessed 09 Oct. 2018].

[6] Sonoluminescence: How Bubbles Turn Sound into Light:
S. J. Putterman and K. R. Weninger, Annu. Rev. Fluid Mech.**32**, 445 (2000).

[7] Bubble Dynamics, Shock Waves and Sonoluminescence:
Claus-Dieter Ohl, Thomas Kurz, Reinhard Geisler, Olgert Lindau and Werner Lauterborn, Philosophical Transactions: Mathematical, Physical and Engineering Sciences **357** 1751 (1999).