

# Adapting Sonoluminescence to Practical Use in the Linfield College Laboratory

by

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# Abstract

Sonoluminescence is simply the process of turning sound into light by passing a high frequency pressure wave through a flask filled with a solution. This process is fraught with difficulties involving the achievement and measurement of sonoluminescence. This paper addresses some problems that occur during the sonoluminescence experiment and ways to overcome or lessen those problems.

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# Introduction

Single Bubble Sonoluminescence (SBS) was discovered by Felipe Gaitan<sup>1</sup> in 1988 at the University of Mississippi<sup>2</sup>. This process was an evolutionary step from Multiple Bubble Sonoluminescence (MBS). When MBS is studied, the results have always been hard to interpret since MBS deals with the random growth and collapse of large numbers of bubbles. These bubbles then could only be analyzed by taking an average of the many bubbles. This average of “random” events did not lead to very accurate measurements of the process.

Gaitan found that it was possible to levitate a single bubble in an acoustical standing wave. By increasing the pressure amplitude, the levitated bubble will stabilize and emit a blue “glow.” This single-bubble sonoluminescence allowed for better measurements of the phenomenon. Even with this improvement, however, measurements are still difficult to perform.

Some of these difficulties arise from the low intensity of light emitted from the bubble, others from the small size of the bubble. Additional difficulties also occur due to the mere feat of getting a sonoluminescing bubble and keeping it active for any length of time to perform measurements. This thesis will describe some efforts to make the difficult task of studying sonoluminescence more accessible to this department.

# Sonoluminescence at Linfield College

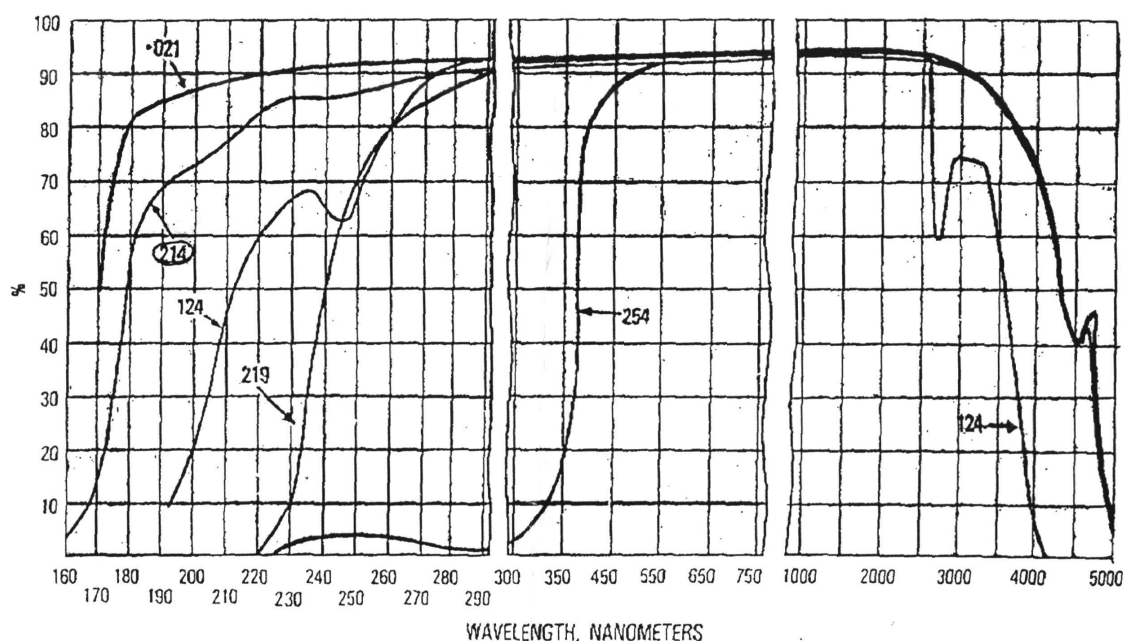
Sonoluminescence at Linfield College was initiated by Dave Evans and Jason Plumlee as an advanced lab project, with the help of Clancy Hinrichs, in the spring of 1995. They followed the set-up and procedure as outlined in Scientific American<sup>3</sup>. Their pursuits in this matter proved fruitless and they eventually abandoned the project.

In the fall of 1997, Robert Poppe and Kris Karpstein, with the help of Donald Schnitzler, resurrected the program and after great efforts were able to achieve sonoluminescence. Deviating slightly from the Scientific American article, they replaced the two 10-mH inductors with two variable inductors to allow for easier tuning of the circuit. Poppe and Karpstein went on to examine the effects of achieving sonoluminescence in solutions other than pure water.

At the conclusion of their association with this project, at this institution, the following materials and procedures were available: A set-up as described in Scientific American with the small deviation of the variable inductors as mentioned earlier. Sonoluminescence was performed in a 100 mL Pyrex boiling flask and measurements were taken using a Hitachi F4500 fluorescence spectrophotometer. To achieve sonoluminescence, tune the voltage source to a frequency that from previous experience was near the frequency required for sonoluminescence with that particular flask. Bubbles are then introduced to the flask and the frequency is adjusted until either sonoluminescence is achieved, or the water has become too gaseous, from the introduction of air bubbles, to continue.

# Adaptation

The first thing done to adapt sonoluminescence to more practical use at Linfield College was to discard the Pyrex flask that had previously been used and replace it with a quartz flask (made of GE-214). This new cell is necessary for recording the lower wavelengths that had previously been absorbed by the glass. Quartz does not vary significantly from Pyrex in its transmission of light waves until wavelengths below 220 nm, as seen in Figure 1.<sup>4</sup>



**Figure 1.** The 214 line is the transmittance curve of the GE-214 quartz flask. 021 is transmittance of GE-021, a material that has an even lower wavelength cut-off than GE-214. Unfortunately at the time of this writing, the GE-021 flask has proved to not work successfully for achieving sonoluminescing bubbles.

Immediately after the quartz flask was set up and functioning, work was started on getting a second full system put together. This second system was a much-needed addition to the sonoluminescence project at Linfield due to the increase in personnel. With the expansion from a single two-person team of students to two teams of two

students, it would be logistically difficult to try to get any amount of work done on a single system.

The creation of a second system seemed like it would be an easy process. It, after all, is merely a matter of getting identical, or similar, pieces and connecting them together. All of the pieces were easy to find except for a sufficient variable inductor. A sufficient variable inductor being one that covers the range of inductance necessary to bring the current and voltage into phase over the frequency required by the flask being used to produce resonance. On the original system, there were two variable inductors, produced by the General Radio Company (and/or Central Scientific Company, both of these companies being listed, in different places, on the casing of the inductors; the determination as to why both names were present remains unresolved). These, when connected in series, covered the range needed for both the original glass flask and the newer quartz flask. Initial attempts to produce a second variable inductor involved disconnecting the two existing inductors and connecting them each to a fixed inductor. Hopefully these both then would give a range that was sufficient.

The two variable inductors however covered two different ranges, one from 1.8 mH to 18 mH and the other from .6 mH to 4.3 mH. The first one when attached with a fixed inductor of 8.6 mH gave a sufficient range. However, the second proved to not offer a range that was adequate for the flasks being used. Therefore, an attempt was made to find other variable inductors around the department while also trying to contact the company to purchase additional ones. Both of these endeavors proved futile. The first produced only ranges that were so large that fine-tuning in the range necessary would not be feasible. The second produced the discovery that these particular items had



stopped being produced 70 years ago, since apparently no one used them anymore. This called for the creation of a variable inductor that would suit the needs of the experiment.

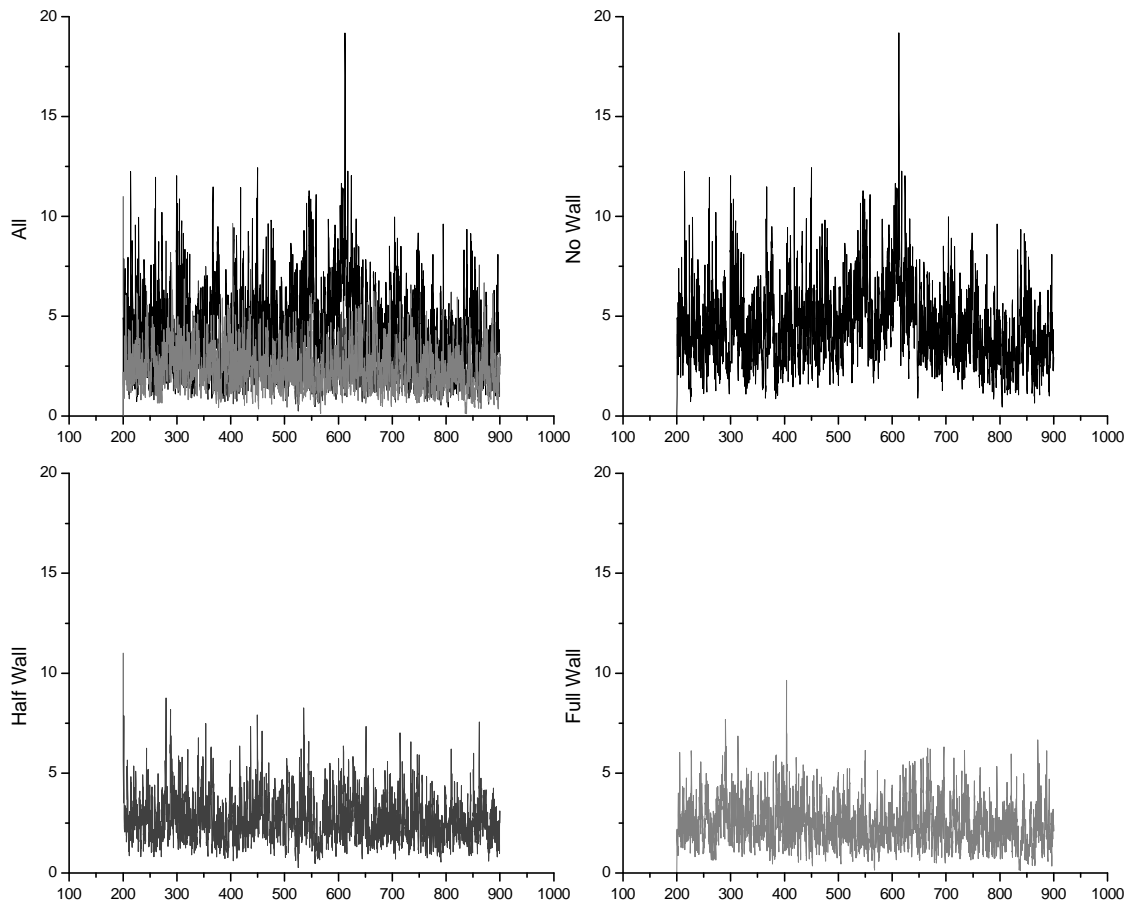
Modeling the new variable inductor after the ones that existed, a rotary inner coil with inductance 5.4 mH, and an outer stationary coil with inductance 10.6 mH, were created. When these two coils move with respect to each other the mutual inductance, due to the presence of two coils, changed producing the variance in inductance. This method gave an inductance range from 7.3 mH to 24.5 mH, which was adequate for the flasks in use. The whole unit was housed in Plexiglas due to its ready availability at the facilities; and to allow an easy view to the insides of the inductor for possible troubleshooting in the future.

At the same time that the second set-up was being finished and the variable inductor was nearing the final stages of its construction, improvements were also being made on data acquisition with the Hitachi F4500 fluorescence spectrophotometer. The spectrophotometer produced results that were of some question, because the chamber where the measurements are performed was left open to allow access for the wiring. This opening was covered with a blanket to help block light, but it was desirable to improve this set-up and cut down on the light that still leaked into the system.

To fix the light leakage problem, four different plates were constructed to go in the spectrophotometer. One went on the bottom to block light leakage coming in through the area vacated by the cuvette holder that typically sits in the meter (This was removed so the flasks could fit inside the detector.). A second plate was constructed to replace a side panel. The existing side panel was removed and replaced with the constructed one, which had three insulated BNC male – male connectors to allow the wiring in and out of

the measurement chamber without having to leave the chamber open. The third and fourth plates were constructed as front panels to hold an exterior front panel in place (This panel had previously been held in place by the cuvette holder previously mentioned and removed.). The two front panels were made of two different heights, a taller one to minimize light leakage over the top of the panel and a shorter one that allowed easier access to the flask within. Usage of the taller plate showed limited improvement over the shorter, so it was deemed unnecessary and its use was abandoned in favor of the shorter.

(Figure 2)



**Figure 2.** These graphs show the amount of background light present in the Hitachi F4500 under three different circumstances and with all three superimposed. No wall corresponds to the absence of any front panel. Half wall is the presence of a half height front panel. Full wall is a full sized front panel. All is the other three graphs graphed on the same axes. Intensity is in arbitrary units, and wavelength is in nanometers.

Once this light leakage problem was solved, another problem that was associated with the spectrophotometer was addressed. The sonoluminescing bubble grows and collapses once each acoustical cycle.<sup>5</sup> This is over (for a typical driving frequency) 28,000 times per second. It takes the spectrophotometer about 2.5 minutes to run a scan of the wavelengths between 200 nm and 900 nm. This means that the bubble has expanded and collapsed over 4,200,000 times during the length of the scan. This is worrisome since during those 4 million collapses and re-expansions the system could have changed drastically. In fact, the system is changing, as evidenced by the fact that as time moves forward, the frequency and amplitude must be adjusted to keep a sonoluminescing bubble from extinguishing itself. So efforts were made to look for a way to combat this change.

It was determined that whatever was changing the system, and forcing the compensation of changing the driving frequency and amplitude, was not related to the number of collapses and expansions of the bubble, but to the “constant” factors of the apparatus. Cold degassed water was used in the experiments since the resulting sonoluminescing bubble increases in intensity as the water temperature is dropped closer to 0° C,<sup>6</sup> and thus a brighter light was produced, making the illumination easier to detect. As time goes on, since the room was not at 0° C, the water temperature comes up closer and closer to the room temperature. Not only does this increase in water temperature affect the brightness of the bubble, but it also changes the resonance frequency of the flask/water system. The resonance frequency of a sphere is

$$f = \frac{v}{2r} \quad (1)$$

where  $v$  is the speed of sound in the medium and  $r$  is the radius of the sphere. Neglecting the flask and only considering the water, it is possible to determine the speed of sound in water at a given temperature from the two given quantities<sup>7</sup>

$$v = 1496.7 \pm .2 \text{ m/s for water at } 25^\circ \text{ C}$$

$$\frac{-\Delta v}{\Delta T} = -2.4 \text{ for water}$$

From these one can extrapolate the following, neglecting the  $\pm .2$

$$v = 1436.7 + 2.4 T \quad (2)$$

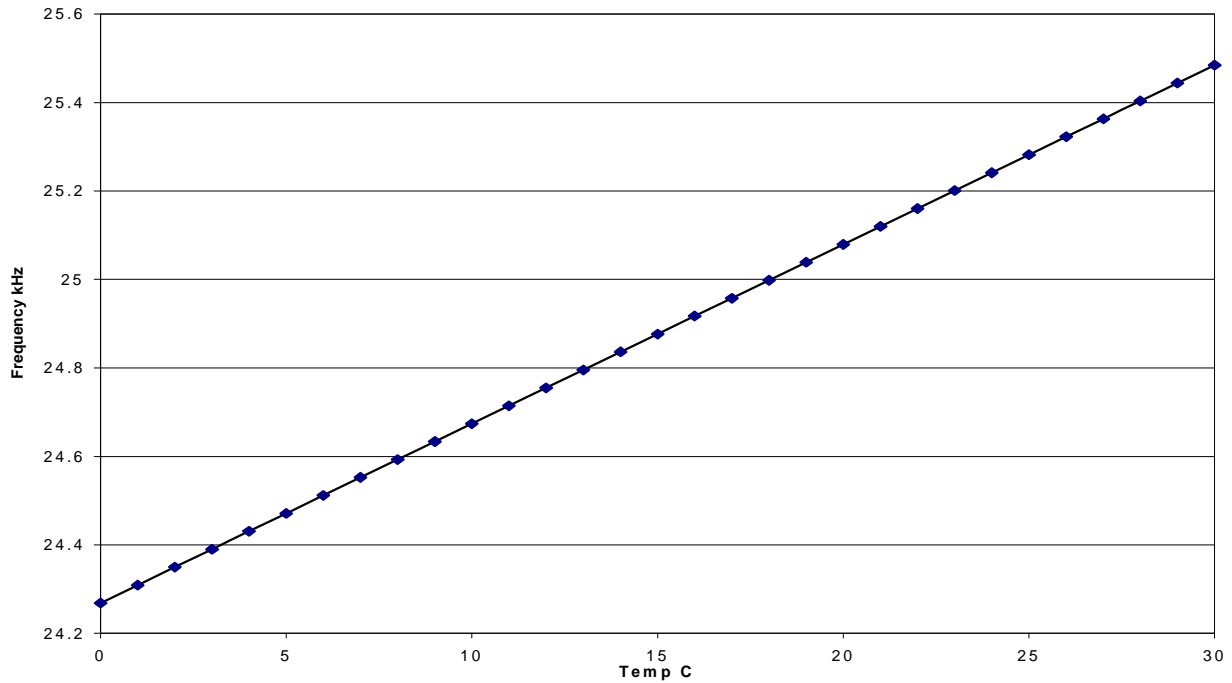
where  $T$  is in degrees Celsius. Plugging 2 into 1 gives

$$f = \frac{1436.7 + 2.4T}{2r} \quad (3)$$

The radius of the water contained in the flask was determined making use of the known volume of water contained in the flask,  $V=109 \text{ mL}$

$$r = \left( \frac{3V}{4\pi} \right)^{\frac{1}{3}} = 2.96 \text{ cm} \quad (4)$$

Thus, the graph in Figure 3 can be produced showing the relationship between water temperature and needed driving frequency.



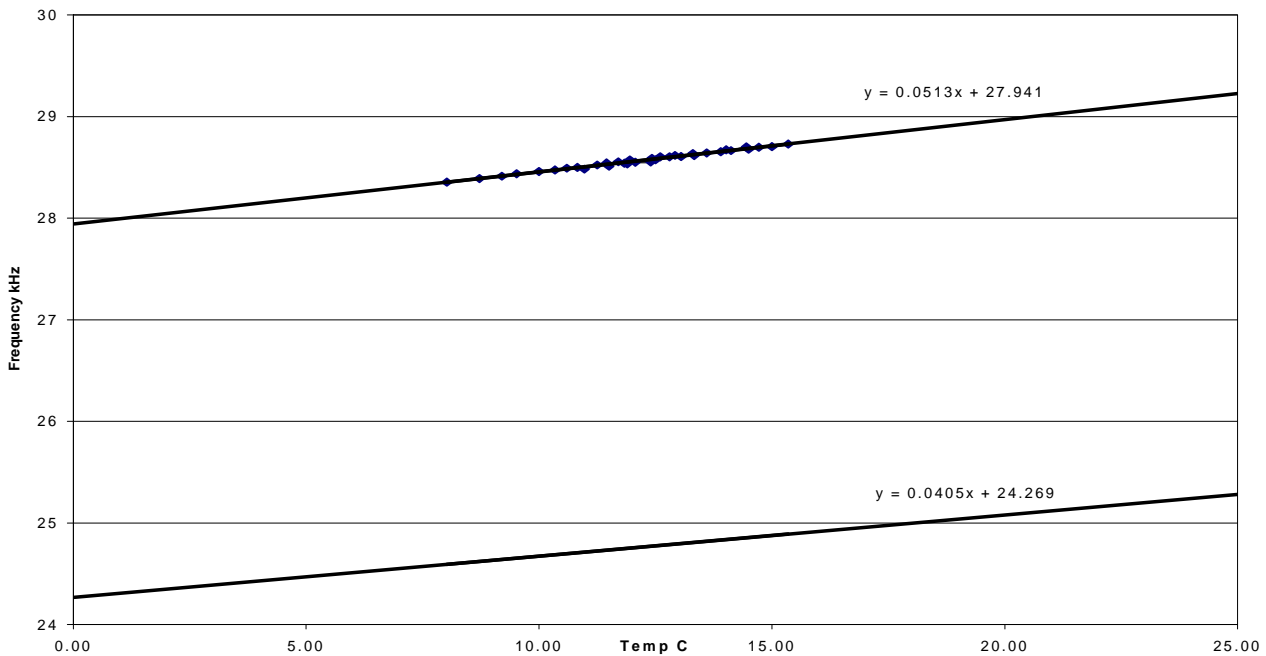
**Figure 3. Theoretical frequency dependence on temperature.**

This result was quite a bit off from the actual frequencies with which the circuit had been run at that had proved successful in driving the system. However, the curve in Figure 3 was produced neglecting the flask. To determine the actual effect of temperature on the resonance frequency, water temperatures were measured, when it was possible to produce glowing bubbles, to find an experimental relationship between water temperature and frequency. This experimental relationship should be similar to the theoretical one that was just derived. Some results of the measurements are in Table 1.

Temp C	Recorded kHz	Predicted kHz	Difference kHz	Percent Diff %
8.02	28.353	24.594	3.76	13.26
8.72	28.389	24.622	3.77	13.27
9.20	28.413	24.642	3.77	13.27
9.52	28.436	24.655	3.78	13.30
10.00	28.459	24.674	3.79	13.30
10.34	28.474	24.688	3.79	13.30
10.60	28.491	24.698	3.79	13.31
10.82	28.499	24.707	3.79	13.30
10.97	28.482	24.713	3.77	13.23
11.25	28.523	24.725	3.80	13.32
11.45	28.543	24.733	3.81	13.35
11.50	28.511	24.735	3.78	13.24
11.70	28.555	24.743	3.81	13.35
11.83	28.540	24.748	3.79	13.29
11.90	28.535	24.751	3.78	13.26
11.95	28.571	24.753	3.82	13.36
12.07	28.550	24.758	3.79	13.28
12.40	28.553	24.771	3.78	13.24
12.42	28.589	24.772	3.82	13.35
12.50	28.573	24.775	3.80	13.29
12.60	28.603	24.779	3.82	13.37
12.80	28.604	24.788	3.82	13.34
12.92	28.617	24.792	3.82	13.36
13.05	28.606	24.798	3.81	13.31
13.30	28.636	24.808	3.83	13.37
13.33	28.615	24.809	3.81	13.30
13.60	28.640	24.820	3.82	13.34
13.90	28.652	24.832	3.82	13.33
14.02	28.671	24.837	3.83	13.37
14.12	28.665	24.841	3.82	13.34
14.45	28.700	24.854	3.85	13.40
14.50	28.678	24.856	3.82	13.33
14.72	28.697	24.865	3.83	13.35
15.00	28.703	24.877	3.83	13.33
15.35	28.728	24.891	3.84	13.36

**Table 1.** This table shows the frequencies needed to achieve stable sonoluminescence at various temperatures along with the theoretical value and the difference and percent difference between the two. All measurements in this table were taken with a 13.8 V peak to peak voltage.

All of the measured data is about 3.8 kHz apart from the theoretical data confirming the anticipated trend-line. Figure 4 shows both the theoretical line and measured data points along with a line fitted to those points. It is possible to use this graph, and a temperature probe, to achieve sonoluminescence easily without the previous hassle of having to scan through a wide range of frequencies. By first finding the temperature of the water, then consulting the graph and dialing into the function generator the corresponding frequency, a lighted bubble is produced. This method proved to work within 30 seconds over 90% of the time.

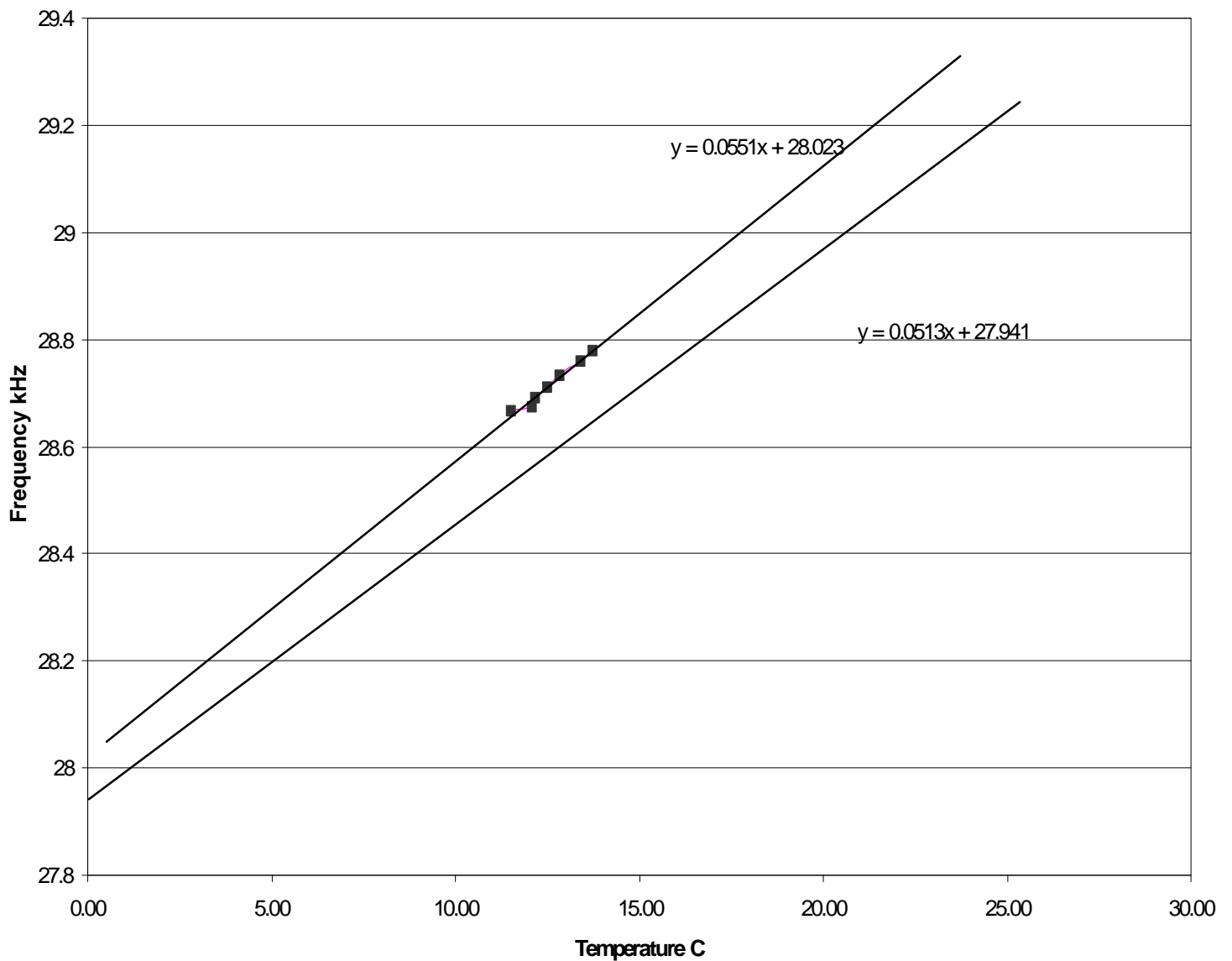


**Figure 4. Measured values and trend line on the top. Theoretical line on the bottom. Measured values taken with a 13.8 V peak to peak voltage.**

In addition to the measurements at 13.8 V, (the typical voltage at which the circuit was driven.) measurements were also taken at 10 V. The lower driving voltage required a slightly higher driving frequency than the 13.8 V measurements. Table 2 contains some values at 10 V and Figure 5 has these values plotted next to the 13.8 V line from Figure 4.

Temp C	Recorded kHz
11.50	28.666
12.07	28.675
12.17	28.691
12.50	28.711
12.82	28.734
13.38	28.761
13.71	28.779

**Table 2. Recorded frequencies and temperatures at 10 V peak to peak.**



**Figure 5. Graph and trend-line for Table 2 along with 13.8 line from Table 1.**



A reliable way to achieve sonoluminescing bubbles in the flask was now available, but there was still the problem of the water heating up to room temperature while measurements were being taken. It was decided that necessity called for using water that was at room temperature at the start of the experiments. That way the water temperature would remain constant instead of creeping up from a colder temperature to the room temperature. However, attempts at this were made during a heat wave and it was impossible to produce bubbles in the resulting warm water. Even after extrapolating the temperature/frequency curve up to the current room temperature, there was no success at finding the correct driving frequency. So work was started on controlling the room temperature to something that it was possible to work with.

Fortunately, in the room one removed from where the sonoluminescence experiments were performed, there was an old broken air-conditioner. Work commenced on fixing it, then fashioning ductwork through a door, into the next room, and then in through the door to the room with the sonoluminescence equipment. This system got the room down to about 14° C and was quite sufficient for producing bubbles that lasted for some time.

After a visit to the University of Washington, the benefit of using a hydrophone with the experiment was observed. This device, when placed in the center of a flask, would allow one to tune the cell to its resonance frequency without consulting any charts or using the hunt and search methods of the past. One of these devices was purchased and it made possible the feat of finally being able to find the resonance frequency for higher room temperature water. Using this hydrophone was a simple matter. It gets

mounted with the tip in the center of the cell and its output is observed on an oscilloscope.

To find the resonance frequency one has only to adjust the frequencies until the peaks of the oscilloscope graphs are maximized. Once this frequency is attained, the hydrophone is removed and a bubble is seeded in the normal fashion. Running the set-up under these normal conditions, it has been possible to achieve bubbles that lasted for over an hour. This was a vast improvement over the initial cold water and warm room that proved (if lucky) to produce bubbles that lasted for maybe five minutes.

Even with this achievement of producing a “stable” bubble that could last for relatively long periods of time, there were still worries about any internal changes in the bubble over the scan times. With the aforementioned 4,200,000 collapses or more that the bubble goes through during one scan using the Hitachi F4500 one could easily imagine that the bubble could be changing, even if only minutely. Some method had to be developed to limit the amount of time it takes to make a measurement. This would remove some trepidation about the “stable” bubble and the data garnered from it.

One way to reduce the scan times was to start using the Chem2000 by Ocean Optics. This device is a photo-diode array that measures the whole spectrum in one chunk instead of scanning across wave lengths like the photo-multiplier tube in the Hitachi F4500. Within the limitations of this machine, this would allow a full measurement of the spectrum in as little as 3 msec. Needless to say, that speed would be wonderful, but with the experiment, it is not possible to sample at that speed due to the low light output of the bubble and the sensitivity of the Chem2000 system.

Ocean Optics has information listed that the Chem2000 needs at least 1,000 photons entering the detector to function correctly. Now assume a typical driving frequency of 28 kHz with an estimated 1,000,000 photons per flash.<sup>8</sup> If there is an even spherical distribution at a radius of 4 cm (4 cm being the distance from the bubble to the detector), then there is a photon density/sec of

$$\frac{28 \times 10^9 \text{ photons/sec}}{\pi 16 \text{ cm}^2} = 5.57 \times 10^8 \text{ photons/cm}^2 \cdot \text{sec} \quad (5)$$

The area of the Chem2000 detector is .001256 cm<sup>2</sup> so if one were to sample for 1 sec there should be 700,000 photons hitting the detector. This is well within the needed value for the detector. As of this date though, No signal has been recorded with the Chem2000 from the sonoluminescence experiment.

A possible problem is that the fiber optic probe that is used with the Chem2000 is very directionally sensitive, and its aperture is only .4 mm in diameter. This makes aiming it in such a way as to pick up a sonoluminescing bubble a difficult task. To abate this problem, a device is currently on order that will allow the fiber to accept light from a larger solid angle than it currently will accept. This should allow enough of an error margin on the aiming of the fiber to allow sampling of the sonoluminescence spectrum successfully with the Chem2000.

Another way that to reduce the scan time is to change the parameters of the spectrophotometer. The Hitachi F4500 had previously been running in phosphorescence mode. This mode allowed for a maximum speed of 240 nm/min. However, there was no reason why the spectrophotometer had to run in phosphorescence mode, it was just something that had been done since the onset of the project. Therefore, the settings were

changed to luminescence mode and scans are now possible at much faster speeds.

Currently scans are being performed on the Hitachi F4500 at 2400 nm/min and scans with this setting take less than 20 sec to complete.

## Future Adaptations

Although the Sonoluminescence program at Linfield College has been improved, there are still many things that can be done. A piece has already been ordered for the Chem2000 that will hopefully allow that system to be used as a complement to the Hitachi F4500. This will not only enable one to check the data of the two different machines but, allow us to perform measurements on two different systems at the same time instead of having to toggle use of the spectrophotometer. The department is also working on getting a non-spherical flask to produce sonoluminescence. In combination with this, different sized transducers are being used to drive the resonance.

The physical aspect of achieving a sonoluminescing bubble has become easier and even possible in weather conditions in which before there were problems with trying to produce sonoluminescence. Nevertheless, at times, there are still problems, and it would be nice to keep working at ways to improve the technique to combat these problems.

The method of introducing bubbles into the system, (by extracting and shooting back in a small amount of water with a syringe or pipette) often introduces much more air into the water than intended. The department has considered, and even a small attempt was made previously, to build a small micro-boiler. This device would consist of a small piece of high resistance wire that a current would be passed through and thus cause the water surrounding it to boil slightly, and in so doing introduce a small amount of gas into the water.

Finally, although it has always been known that the flask/water system absorbs different amounts of light at different wavelengths, an attempt has never been made to correct this problem. The obtaining of correct transmission curves for each of the flasks in use and for the amount of solution contained in them is a prerequisite for the correction of the intensity curves. Once valid transmittance at the various wavelengths has been established, it would be beneficial to create a program that one could feed data into and have it produce a corrected data set. Into this program one could also insert a smoothing algorithm to lessen the high amounts of jagged peaks always found on the scans (for an example of this “problem” look again at Figure 2.). This resultant corrected and smoothed data set would then offer a more accurate picture as to what exactly the sonoluminescing bubbles are doing.

## Acknowledgments

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## References

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<sup>1</sup> L.A. Crum, *Physics Today* 47, 22 (1994)

<sup>2</sup> F.B. Seeley and C.K. Joens, *American Journal of Physics* 66, 259 (1998)

<sup>3</sup> Robert A. Hiller and Bradley P. Barber, *Scientific American* 272, 96 (1995)

<sup>4</sup> Graph furnished by Quartz Scientific, Inc.

<sup>5</sup> F.B. Seeley, A. Bandas, M. Fowler, and R. Gibson, *American Journal of Physics* 67, 162 (1999)

<sup>6</sup> Seth J. Putterman, *Scientific America* 272, 46 (1995)

<sup>7</sup> Robert C. Weast, *Handbook of Chemistry and Physics* 56<sup>th</sup> ed., E-47 (1975)

<sup>8</sup> B.P. Barber et al. *Phys. Rep.* v.281 N2 (1997)

<sup>9</sup> est. Jun 1999 Gust-Mat Scientific Supply “Big Toys for Little Minds”<sup>TM</sup> Headquarters  
in Graf Hall, Linfield College