

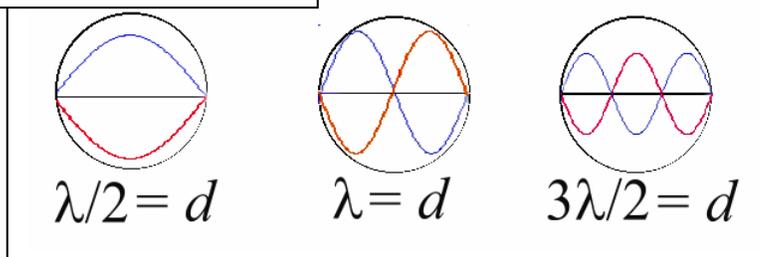
Abstract

Acoustic cavitation and collapse of a solitary gas bubble in an otherwise degassed liquid medium results in photon emissions. The mechanism triggered by this collapse, which leads to the emission, is unknown. This photon emission lasts only pico-seconds and is often very faint. We intend to leave a functioning sonoluminescence apparatus for future research. To achieve these ends we will tune a resonating circuit to the resonating frequency of the flask to create an acoustically cavitating bubble.

Introduction

To trap and illuminate a bubble of air, a circular vessel of liquid must be resonated. Resonance is the

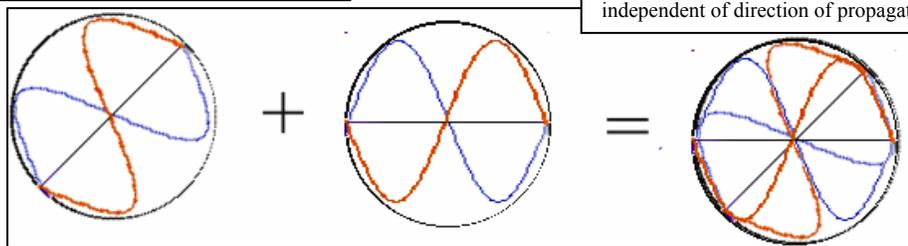
Examples of standing waves



most efficient disturbance of the vessel and liquid medium. Resonance can be characterized by a standing wave in the vessel by relating the vessel's diameter d to the disturbance's wavelength $\lambda \rightarrow n\lambda/2 = d$.

The vessel must be nearly circular so that the resonant frequency is not dependant on the direction of propagation.

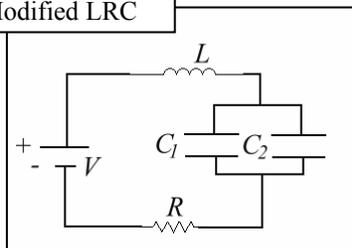
Circular vessel \rightarrow the resonant λ is independent of direction of propagation



A disturbance with the desired λ can be made using transducers purchased in a set from Channel industries. The transducers start an ultra sound wave through the vessel. This wave propagates through the vessel with velocity v . $v = \lambda f_d \rightarrow f_d = v/\lambda$. Let $\lambda = d$ so $f_d = v/d$. The transducers are driven most efficiently by a circuit with the same resonant frequency f_d . A circuit that resonates at f_d will deliver both electrical current and voltage in phase with the disturbance in the vessel.

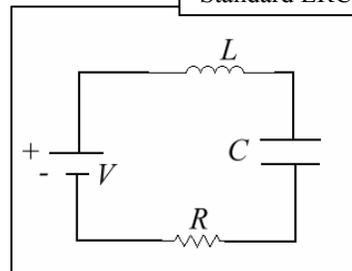
In a standard resonant circuit a resistor, inductor, and a capacitor are wired in series with a resonant frequency $f_e = \frac{1}{2\pi\sqrt{LC}}$ where L is the inductance of the inductor and C is the capacitance of the capacitor.

Modified LRC



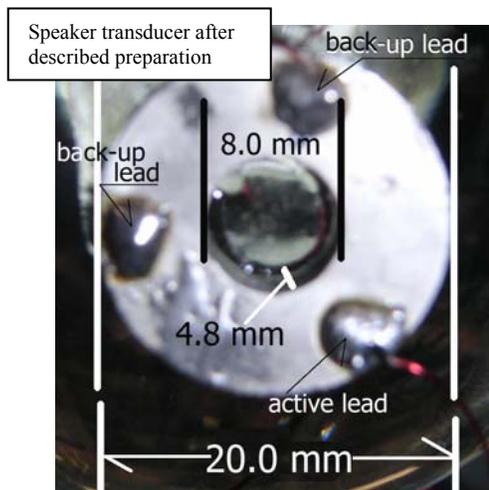
In our modified LRC circuit the capacitor is replaced by transducers (C_1 and C_2 in the figure to the left) with factory specified capacitance and the inductor chosen to have inductance L such that $f_e = f_d$.

Standard LRC



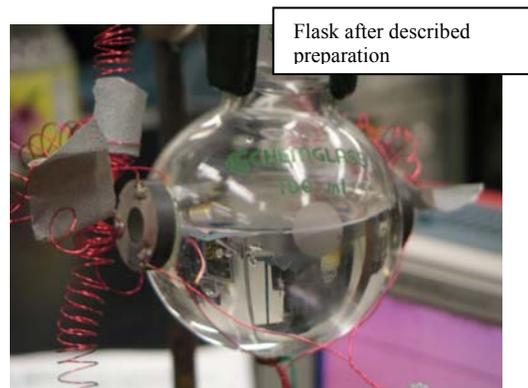
Procedures

The focus has been on recreating an experiment proposed by Hiller and Barber in the *Scientific American* February 1995 publication. The following procedure is an attempt at recreating that experiment as closely as possible with available materials.

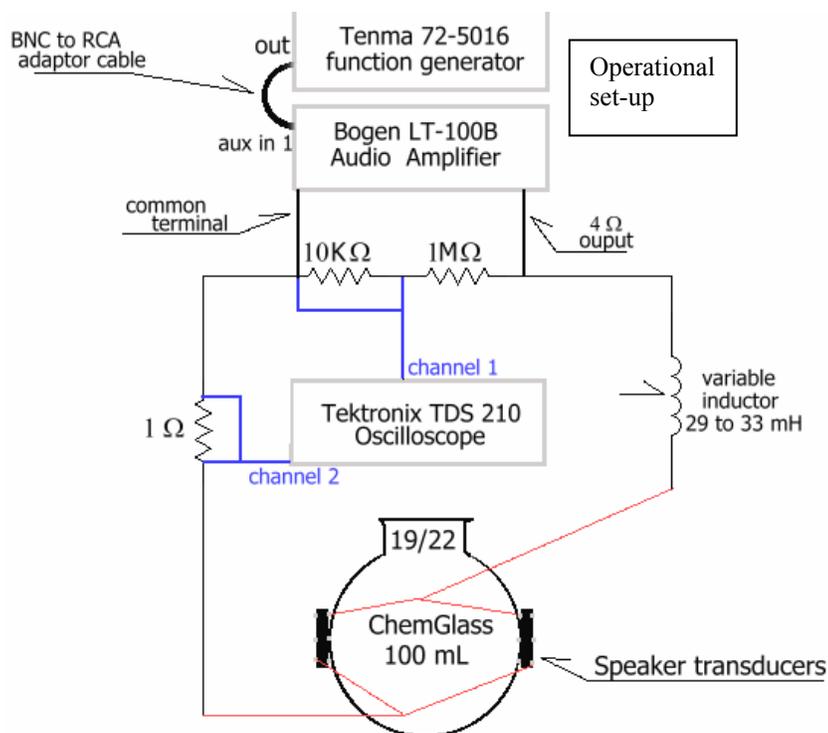


Transducer preparation: A set of three piezoelectric transducers, two speakers and one microphone, were purchased from Channel Ind, as described by [William Andrew Steer](http://www.techmind.org) Ph.D. on [techmind.org](http://www.techmind.org) as well as Hiller and Barber (Hiller, 96). We soldered three leads (28 gauge wire) on each side of the speaker piezoelectric transducers with extra leads serving as back-ups. Hiller and Barber used 36 gauge wire (S.A., 96) and Steer used wire with a 0.2 mm diameter ([techmind.org](http://www.techmind.org)). 0.2 mm (metric 2) wire is between 33 and 32 gauge. We evenly spaced the leads into a tripod configuration to allow for better contact with the flask.

Vessel Preparation: The transducers were aligned in direct opposition to each other on the flask by aiming a laser through their centers and through the flask. The side of the transducer with the red (positive) electrode was glued towards a 19/22 Chemglass, round-bottomed 100 mL flask with quick drying epoxy and allowed to set for 24 hours with loose fitting clamps. We soldered leads to each side of the microphone transducer and glued it to the bottom of the flask.

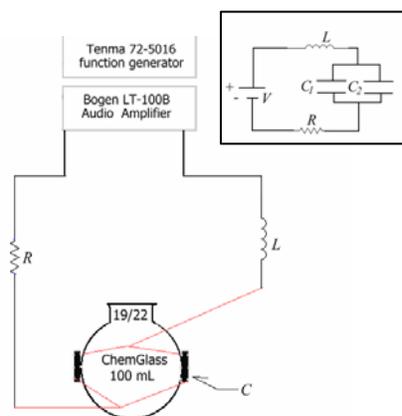


The Circuit: The diagram below shows our circuit that drives the transducers.



The Bogen amp was provided by TESC Media Loan. All other equipment was provided by lab stores.

Notice the semblance of a standard LRC when the oscilloscope is removed.



We let $\lambda=d$, as Hiller and Barber did. This means that the circuit must be made to resonant at $f = v/d$, which is the theoretical resonant frequency for the vessel. Ultrasound propagates through water at $v=1440$ m/s according to Giancoli (418) and at $v=1500$ m/s according to Hiller and Barber. Our flask has a $d = 60.5$ mm making $f_d = 23.8$ kHz or 24.8 kHz. For either case v is different for the sound propagating through the glass walls of the vessel. To account for this Hiller and Barbers suggests increasing f_d by 10 percent which results in our $f_d = 27.3$ kHz or 26.2 kHz. This f is just an estimate for the resonant frequency of the vessel. The circuit was made to vary it's resonant frequency around these possible vessel resonant frequencies.

The electrical resonant frequency $f_e = \frac{1}{2\pi\sqrt{LC}}$ Solving for L results in $L = \frac{1}{(2\pi f)^2 C}$. The

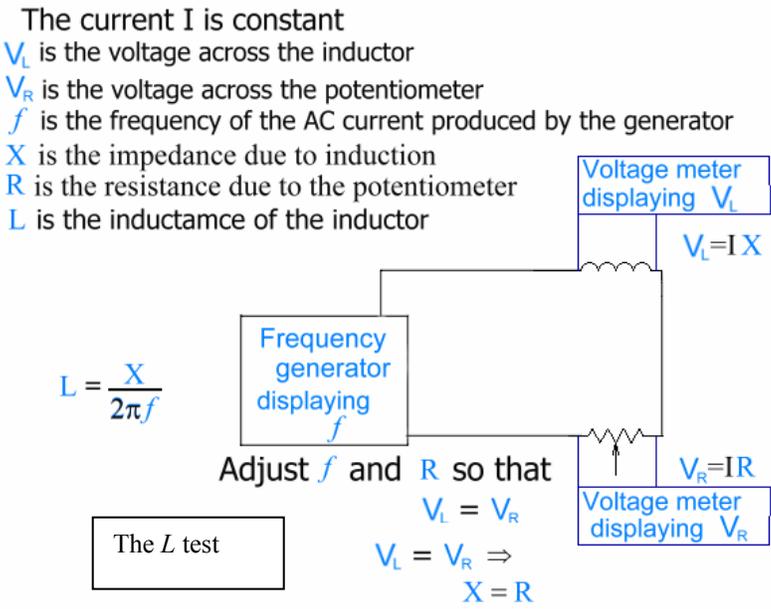
capacitance of each transducer is factory specified to be 700 pica-farads $\rightarrow C_1+C_2 = C = 1400$ pico-Farads. So to cover a range of frequencies form 23.0 kHz to 28.5 kHz (which covers all discussed possible f_d), L must be able to be varied from

$$L = \frac{1}{(2\pi \cdot 23 \cdot 10^3 \text{ Hz})^2 (1400 \cdot 10^{-12} \text{ F})} = 34.2 \cdot 10^{-3} \text{ H to}$$

$$L = \frac{1}{(2\pi \cdot 28.5 \cdot 10^3 \text{ Hz})^2 (1400 \cdot 10^{-12} \text{ F})} = 22.2 \cdot 10^{-3} \text{ H} .$$

Inductance: The items that have inductance that vary in this range (spools of wire and self wrapped inductors) do not come with the inductance value measured. A method for measuring inductance was adapted from <http://www.oz.net/~coilgun/theory/measureinductance.htm> by Barry Hensen. In our version of the

experiment (*L Test*) a 20K ohm potentiometer is wired in series with an inductor of undetermined inductance L . The system is driven by a Tenma 72-5016 frequency generator. As in Barry Hensen's set-up the voltage across both the resistor and the inductor is monitored. Unlike Barry Hensen's our set-up monitors voltages constantly on dedicated meters. The idea of the experiment is to adjust the potentiometer and frequency until the voltage across the inductor equals the voltage across the resistor. At this point the resistance R of the potentiometer equals the impedance



due to induction $X \rightarrow R=X$. Since $L = \frac{X}{2\pi f}$ where f is displayed on the frequency generator, a resistance

measurement across the potentiometer allows for the calculation of induction.

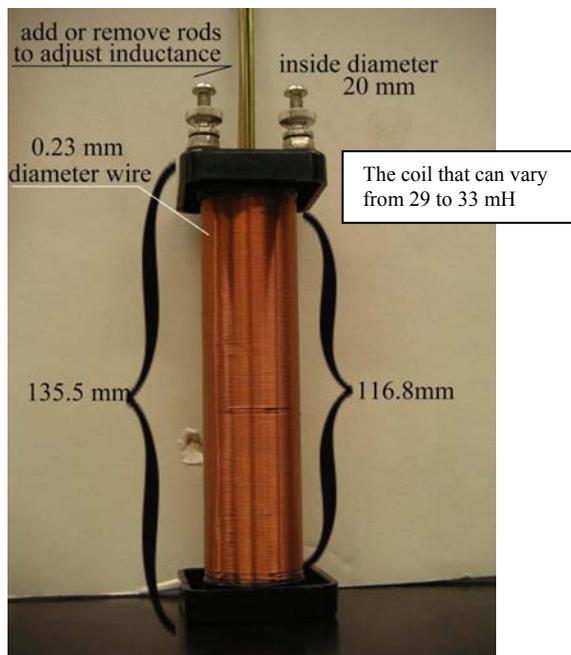
A coil of wire has an inductance that can be varied by the insertion of metal through the center of the coil. Several inductors were tested both empty and full of metal rods (rod were cut from wire cloths hangers) to determine their range of inductance. The best inductor we found for varying inductance allowed us to vary from 29 to 33 mH. This allows the circuit to resonate at frequencies between 25 kHz and 23 kHz. This range does not include all possible resonant frequencies for the vessel.

Microphones: We did not understand the signal from the peizoelectric microphone that came with the speaker transducers so we used a Vernier amplified microphone with LoggerPro software.

Finding *f*: I have already shown that, theoretically, the vessel's resonant frequency $f_a = v/d$. That combined with Hiller and Barber's adjustment for the glass led to estimates for the resonant frequency of the vessel. These estimates gave us a place to look for the actual resonant frequency of the vessel. The operational set-up was connected just like in the figure on page 2 labeled "operational set-up". The coil was left empty ($L = 29mH$) so that the theoretically f was 25 kHz. The frequency generator was adjusted until the voltage and current (both channels of the oscilloscope) were in phase. This occurred at $f = 28.3$ on the frequency generator. At this point the circuit is in resonance and the amplitude of the both the current and voltage hit the maximum.

The Vernier microphone picks up the strongest signal when the circuit is in resonance. By disregarding the peak that occurs at the circuit's resonant f we could look for the vessel's resonant frequency. As we slowly sweep through the frequencies 23 to 30 kHz we look for peaks in the microphone signal that occur at frequencies other then 28.3 kHz. The other peaks indicate frequencies for which $n\lambda/2 = d$. Once a peak other then 28.3 kHz is found a new inductance is chosen (by adding rods through the center of the inductor) so that the resonant frequency of the circuit matches that of the vessel. This match was never achieved due to the unreliability of the amplifier.

The water: The water in the vessel must be clean, cold, distilled, and degassed. To do this we cleaned a one liter Pyrex bottle and the vessel with soap, then with ethanol ,and rinsed them out many times with distilled water. We boiled 200 mL of water in the one liter bottle on a mantel. Once the water was boiling we removed the bottle from the mantel and sparged helium through the water. After 10 minutes the bottle was placed in an ice bath and the sparging continued for 40 minutes. Ice was replaced twice during the forty minutes. After the water was cold, about 15° C, 100 mL of it was place into the vessel with a 25 mL pipette.



Injection: We adjusted the circuit to as close to resonance as we could. Then we used a syringe to inject a bubble of air in to the vessel of water. We found the bubble to move awkwardly in the vessel but always move to the top of the vessel and escape. We never trapped or illuminated a bubble.

Conclusions

W.A. Steer wrote (and I feel the same way) "I found the article [Hiller and Barber's 1995 article] to be quite correct ... but ...it fails to emphasize some significant details... (W.A. Steer)." For instance, the 36 gauge wires in the published set-up are connected directly to coaxial cables of greater (less gauge) and un-specified thickness with out elaboration on why such thin wires were used.

We were not successful in the creation of a functional sonoluminescence chamber but learned much that can be helpful to future attempts. Obtaining sonoluminescence is not as easy as some popular articles suggest. A higher quality amplifier is needed. A long spool of wire might give larger and more appropriate range of inductance. The use of a different vessel with more carefully prepared transducers might also be helpful.

A nearly circular vessel is important. A large neck size distorts the circular shape of the vessel. Our vessel was the smallest necked round bottom flask in TESC lab stores. The flask that Dr. Steer used was a distillation flask [Griffin and George part FHD-230-030G] (<http://www.techmind.org/sl/sono.html>). I could not find this flask in the Griffin and George catalog. In any case, a much smaller neck is needed.

The Bogen amplifier's output wave function slowly became distorted as it remained on. At the beginning of our work sessions the signals were perfect but as the session progressed the amplifier behaved worse and worse, producing messy misshapen waves. Poorly prepared transducers contributed to the messy wave problem. These piezoelectric transducers are sensitive to heat. The leads must be soldered on quickly with a single drop of solder. Our soldering technique may have altered the transduction properties of the piezos by exposing them to excess heat.

Inductors must be found that will allow a greater range of resonant frequencies. I suggest a large spool of wire be tested for inductance. That spool could be unrolled until it meets the bottom of the range of inductance. Then its inductance could be varied to maximum with the insertion of metal rods. If the inductance of the spool does not exceed the maximum of the desired range of inductance then a second spool can be unrolled until its inductance matches the maximum of the first spool. Then vary the second spool's inductance by the insertion of metal rods. In this way spool after spool can be prepared with individual complementary inductances. For example spool one might have L from 21-25 mH while spool two has 25-29 mH, three has 29-33 mH and so on.

The biggest factor that must be addressed before the sonoluminescence can be achieved is the power delivered to the transducers. Sonoluminescence is more effectively achieved with over 100 watts and over 600 mV (Claus-Dieter Ohl, 269). We used a 100 watt amplifier but were able to get less then 15 watts of power out of it with less than 200 mV.

References

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- Edward B. Flint; Kenneth S. Suslick, **The Temperature of Cavitation**
Science, New Series, Vol. 253, No. 5026. (Sep. 20, 1991), pp. 1397-1399.
A bubble more easily cavitates in a cold liquid.
- Hiller and Barber. "Producing Light from a Bubble." *Scientific American*. Feb 1995 P 96
This article provides the basic design for the sonoluminescence experiment. This is a basic outline and does not stand alone as a guide to successful sonoluminescence.
- Putterman, Seth. "Sonoluminescence: Sound into Light." *Scientific American*. Feb 1995.
Putterman describes what sonoluminescence is and the principals behind making it.
Sonoluminescence occurs when sonic pressure waves cause the growth and subsequent collapse of microscopic bubbles. Due to the high pressures released during the collapse of the bubbles, energy can be emitted in the form of light, hence sonoluminescence.
- [Steer](http://www.techmind.org/sl/sono.html), W.A. PhD, <http://www.techmind.org/sl/sono.html> last visited on May 30, 2006.
This article is a detailed recreation of Hiller and Barber's 1995 experiment. Sonoluminescence is not as easy to achieve as Hiller and Barber lead one to believe. High power and voltage is required.

The transducers were purchased in a set from

Channel Industries, Inc
839 Ward Drive
Santa Barbara, California
(805) 967-0171

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