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Sonoluminescence: Sound And Light

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An Honors College Thesis

By

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Physics

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Contents

Abstract

The purpose of this experiment was to observe single bubble sonoluminescence. Sonoluminescence is the conversion of sound waves into light and requires resonating a circuit with a flask filled with degassed water. The resonating flask should allow a bubble to balance in the centre of the flask, and in the right conditions should exhibit sonoluminescence and emit light. I used a resonating RLC circuit with piezoelectric transducers acting as capacitors. Whilst I ensured both the circuit and flask were at resonance, I did not observe sonoluminescence. This could be attributed to the low voltage produced by the circuit, or the instability of the function generator.

Acknowledgments

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Introduction

Sonoluminesence is the conversion of sound into light. Sinusoidal waves are passed through a flask of water, and if the bubble is stable and the circuit and flask are in resonance, a repeated flash of light will be produced. The precise mechanism of the genesis is still unknown. I used a RLC circuit where a flask of degassed water with piezoelectric transducers glued to either side acted as the capacitors and as speakers. I used the piezoelectric electric transducers (PZT) to pump the sinusoidal wave through the water. At circuit and acoustic resonance, small bubbles that are inserted into the water and stabilized in the centre of the flask collapsed and emitted blue light. This experiment uses the method outlined in W.A. Steer's article, *Sonoluminescence experiment: sound into light*, combined with the information given in S.J. Putterman's Scientific American article, *Sonoluminescence: Sound into light*. The other cited works have also aided in the experiment and provided further understanding of sonoluminescence. I have outlined how to construct the experiment so that single bubble sonoluminescence can be driven. I have also included how to fix a number of common problems with this experiment.

History of Sonoluminescence

H. Frenzel and H. Schultes of the University of Cologne first discovered sonoluminescence in 1934 (Frenzel and Schultes 421-424) as an indirect result of their research in marine acoustic radars. They were passing strong ultrasonic fields through a water bath when they observed groups of flashing bubbles. This is what is now referred to as "Multi-Bubble Sonoluminescence." They explained their bubbles as a result of a type of electrical friction; they believed that the built up charge emitted light just as rubbing shoes on carpet does. They did no further research on the subject and little advancement was made until 1989.

Researchers' attempts at studying the mysterious bubbles through spectral analysis proved unsuccessful, as the light produced when driving multi-bubble sonoluminescence is inconsistent, and averages and estimations must be made in order to come to any sort of conclusion. In 1989, Felipe Gaitan from the University of Mississippi discovered that by partially degassing the water, he could simplify the experiment (Gaitan, Felipe, Crum & Lawrence 87). He became the first person to drive Single Bubble Sonoluminescence, which is when one drives acoustic vibrations through a single stable bubble and it emits light. He used piezoelectric transducers glued to a cylindrical flask to apply sinusoidal acoustic pressure waves to the bubble, which produced flashes of light. These flashes he discovered were emitted once per acoustic cycle and they lasted approximately 100 picoseconds. Gaitan had found a method that drives Single

Bubble Sonoluminescence. Barber, Seth Putterman, and Bob Hiller used his apparatus setup to make important measurements.

In February 1995, Putterman published his research on Single Bubble Sonoluminescence with Hiller and Barber in The Scientific American (Putterman 46-51) . They used Gaitan's setup and a photomultiplier tube and shone a laser at the bubble to measure its size as the intensity of the light scattered from the beam depends on the square root of a spherical objects' radius. Hiller and Barber observed that the bubble contracts very quickly, within around 50 picoseconds, and then once it reaches its minimum radius, around 0.5 microns, it releases a flash of light. The spectra from the photomultiplier tube showed that most of the light is ultraviolet, and that the temperature inside the bubble exceeds 10,000 kelvin, and if it reached a radius of 0.1 microns it would be 100,000 kelvin. The experimenters also found that small amounts of noble gases increased the intensity of the bubble and changed its color but they did not find any explanation to this. They concluded that while part of the reason light is emitted could be just an expression of energy, there is a degree of energy amplification seen in the temperature of the bubble that does not make sense. Shock waves interfering constructively in the bubble were seen to explain this problem and while in his paper Putterman states that he could not definitively state that this hypothesis is the cause the pulses of light, it has become widely accepted and referred to as "shock wave sonoluminescence."

The physics of the experiment

Detecting Sonoluminescence

Measuring the light produced by sonoluminescence is difficult because the flashes of light occur too quickly for most sensors to detect. One of the instruments that are able to detect the light produced is a photomultiplier tube (PMT). As seen in Fig. 1, PMTs are vacuum tubes that use the photoelectric effect to emit an electron when it passes through a photocathode due to the absorption of a photon. Once the electron inside the tube is emitted it is focused and then ejects a number of electrons onto the next dynode. A dynode is an electrode that multiplies charges, so each time an electron hits a dynode more electrons are released. At the end of the tube there is an anode, which detects the differences in current at each dynode. They have a particularly fast response time of around 10-20ps, which is perfect for measuring sonoluminesence which lasts around 50ps. PMTs and be used to measure UV and infrared light as well as visible light. Since sonoluminescence produces a very weak signal and the spectra is mostly UV, PMTs are the ideal detectors for sonoluminescent light.

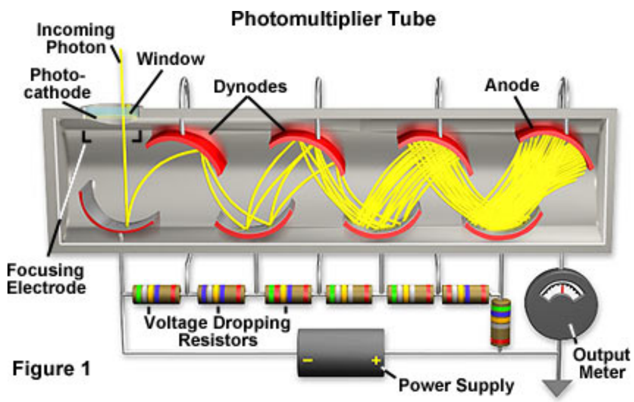

Figure 1. Photomultiplier tube (Davidson Olympus America)

RLC Circuits

An RLC circuit consists of a resistor, an inductor, and a capacitor. This experiment essentially uses an RLC circuit with the piezoelectric transducers acting as capacitors. The current oscillates harmonically in an RLC circuit and each component can be adjusted to find a point of resonance at which the voltage drawn will be a maximum.

The electrical resonance of an RLC circuit depends on impedance matching. Impedance matching is finding the point at which the impedance of the capacitor and inductors are of equal value with the opposite sign. This can be found when the frequency relates to the inductance and capacitance in the following way:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

RLC circuits work by an exchange of energy. The capacitor is charged and then discharges, allowing for a magnetic field to build up around the inductor. The inductor's magnetic field then collapses and recharges the capacitor. The system acts like a simple harmonic oscillator, which is what allows for us to tune the circuit to resonance.

Experiment

Equipment

- **100ml cylindrical flask**
- **2x piezoelectric ceramic rings (diameter 19.9mm, thickness 4.5mm, inner radius 8mm) and 1x piezoelectric ceramic disk, (6mm diameter and 2mm thickness)** - These can be purchased at www.americanpiezo.com with item number 828, and item number 1133. The first two will be used as glued to either side of the flask and used as speakers. The disk will be used as a microphone and glued to the base of the flask. This will be abbreviated as PZT in this paper.
- **Insulated 8 gauge copper wire –** for soldering to PZTs.
- **Wire and banana clips –** for use in the circuit.
- **BNC plugs and coaxial cable –** The plugs will be used at the junction between each of the PZTs, and the rest of the circuit. They cords will be used to connect the microphone to the oscilloscope, and the audio amplifier to the function generator.
- **Soldering kit** - This will be to solder the wire onto the PZTs. The PZTs have a Currie point, which is where they lose their dipole moment, of 450 degrees Celsius. This is also the melting point of solder so soldering must be done quickly. Follow the soldering instructions given.
- **Degassed water** - Single bubble sonoluminescence can only be driven with degassed water. One easy way to degas distilled water is to put a conical flask over a Bunsen burner and bring it to boil. Seal the flask and place it in an ice bath

for three hours. Allow to return to room temperature then the process is complete and your degassed water is ready to use.

- **Resistors** – 1Ω, 5 Ω, and 10Ω resistors were each tried. I ended up using the 1Ω resistor as it was recommended in W.A. Steer's paper.
- **Inductors –** The value of the inductor will depend on the flask frequency and effective capacitance. I used an inductor of 30mH. You can use a variable inductor or use a number of smaller inductors in series to match impedance. This will be explained in further detail in the equipment setup.
- **Oscilloscope –** A standard 2 input channel oscilloscope will suffice and will be used to observe points of resonance.
- **Function generator –** Some experimenters have found that a lab function generator will suffice but others suggest a digital generator is needed. If your function generator is able to remain stable at points of resonance and not fall away than you should be able to achieve SBSL with it.
- **Audio Amplifier –** I used an Audio Source AMP100VS 2 Channel amplifier. The amplifier must be bridgeable.
- **Ring stand**
- **Three finger clamp**
- **Two part Epoxy**
- **Rubbers stoppers fitted to the flask**
- **Small diameter syringe and needle**

Piezoelectric Transducers

In this experiment I use ceramic piezoelectric transducers (PZTs). PZTs convert electrical energy into vibrations. They are polarized when a current is passed through them with one side positively charged and the other negatively charged. When a current is passed through induced dipoles are formed within the transducer as the molecules align with the electric field. This causes them to expand and contract creating sound waves.

Different sizes and shaped PZTs allow for different resonant frequencies when they are attached to the flask. The thicker the PZT, the lower the frequency. I used two PZT rings as speakers attached to both sides of the flask with a connected to the circuit and one small PZT disk attached to the bottom as a microphone connected with the oscilloscope.

Each of the PZTs needed electrodes soldered on to either side. It was important to carry this out efficiently and to be monitor the temperature of the solder, as the Curie point of the PZTs is very close to that of solder melting. In 1895 Pierre Curie discovered that there is a temperature at which magnetic materials lose their magnetic properties (Britannica 1). For our PZTs this means that they would no longer contract and expand with an electric field, as the dipoles would not align. For the PZTs the Curie point is 350 degrees Celsius.

Preparing the flask

The wire must be soldered to either side of the three PZTs. It happens that solder melts at the Currie point (450 °C) of the ceramic used in the PZT, so soldering must be done quickly. It is recommended that you have some background knowledge of soldering, or that you do a few trials with spare pieces of wire before working with your PZTs.

Cut your 8 gauge wire into 10cm pieces and strip back around 1.5cm of the insulation at each end. Twist the wire around a pencil to reduce the mechanical stress on the PZTs. The PZTs must be in phase, meaning that the dots or crosses on one side of the PZTs should all be either facing in or outwards. Soldering three wires to the inside of both the speaker PZTs, and one to the outside, then solder one wire on the inside and outside of the microphone PZT.

Once the solder has cooled, place the flask in the stand and mount the speaker PZTs on either side of the spherical flask, and the microphone at the base using the two-part epoxy as so:

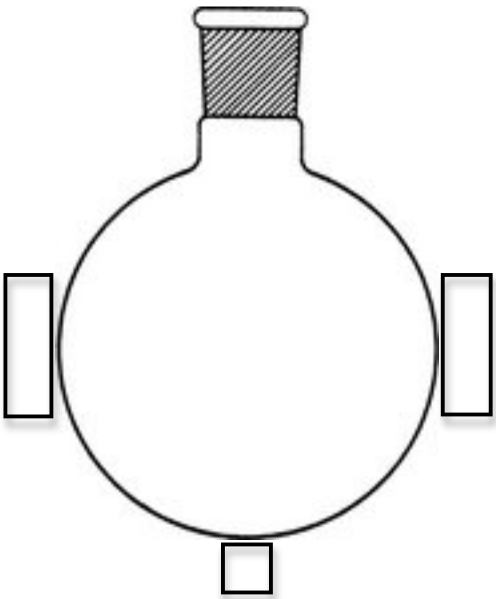

Figure 2. Speaker PZTs on either side of the 100ml flask and the microphone PZT on the base.

Flask Resonance

First, fill the flask with degassed water up to the base of the neck and insert the rubber stopper.

In order to find flask resonance, connect the speaker PZTs in parallel to the audio amplifier, which should be connected with the function generator

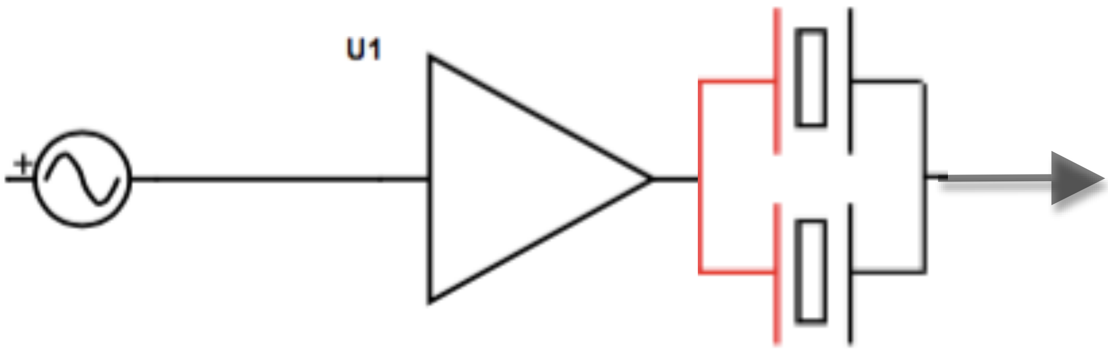

Figure 3. Speaker piezos in parallel with function generator.

Connect the microphone PZT to the oscilloscope to observe the voltage output whilst the frequency is slowly increased. Resonance is when there is a noticeable increase in voltage, and it can help to use the second channel of the oscilloscope to compare the output directly from the function generator. Record the points at which there is the strongest acoustic resonance. This should be found between frequencies of 25kHz to 27kHz and can be confirmed if squeezing the flask creates a significant drop in amplitude.

Circuit Resonance

After finding the peak acoustic resonance point, the electrical resonance must be found. Since the PZTs act as capacitors in this circuit and in order to resonate the circuit a variable inductor is added in parallel with the audio amplifier and the PZT. Since this will act as an RLC circuit a resistor must also be added in parallel with the inductor. I used a resistance of 1 ohm. Vary the inductor until you see the signal reach a maximum. This point can be calculated using this equation, if the resonant frequency of the circuit and the capacitance of the PZTs is known by

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\pi\sqrt{LC}}$$

The signal should increase by at least by a factor of two at resonance. If you are having trouble impedance matching, start at a low inductance and increase until you see a significant peak. The inductance found with my PZTs was 32mH but others have found resonance between 1-70mH. If you think you have found a point of resonance, tap the flask and the signal should decrease to the acoustic resonance point you had before the inductor was added. The signal should be a clean sine wave and sonoluminescence will only occur if the amplitude is at least 2-3V. If your circuit is not pulling enough voltage, make sure that the volume on your audio amplifier is at its maximum and try impedance matching at other acoustic resonances points.

Observing Single Bubble Sonoluminescence

While the circuit is still in resonance, take the rubber stopper off the flask. Using a syringe and needle take a small amount of degassed water in from the flask. From around one or two centimeters above the water, use the syringe to drop one or two drops of water into the flask to make the bubbles. Monitor the number of bubbles being produced and try to reduce this to one or two. The bubbles should stabilize at the centre of the flask with some practice.

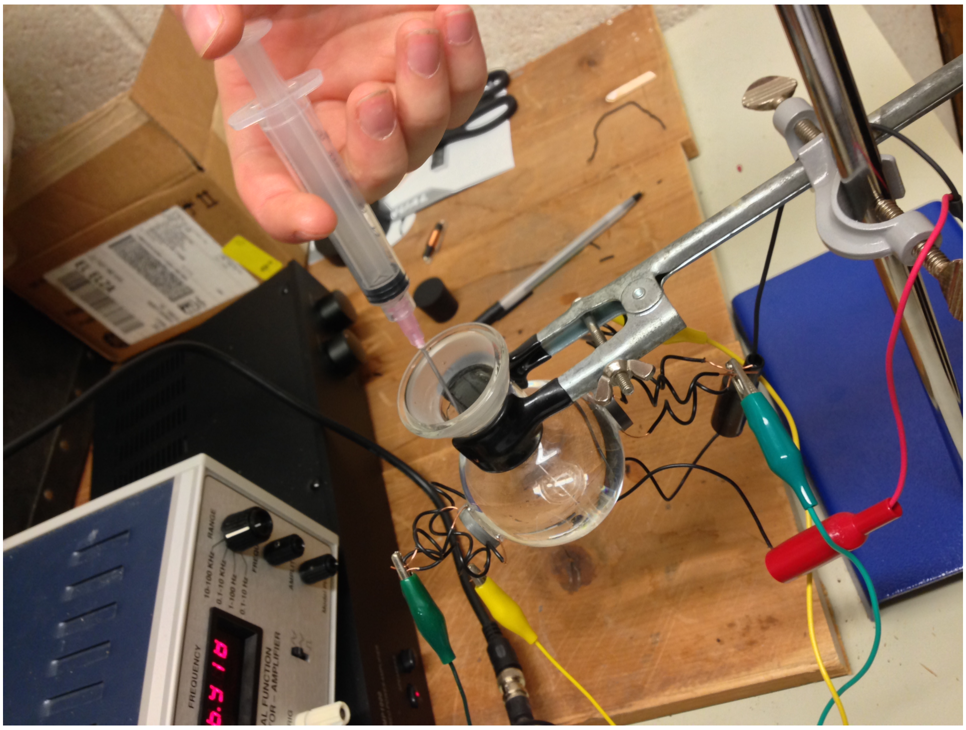

Figure 5. Using a syringe and needle to produce bubbles

The amount of dissolved gas in the water affects the bubble's stability even 24 hours after the water is degassed. W.A. Steer's graph outlines these effects and the voltages needed for sonoluminescence to occur.

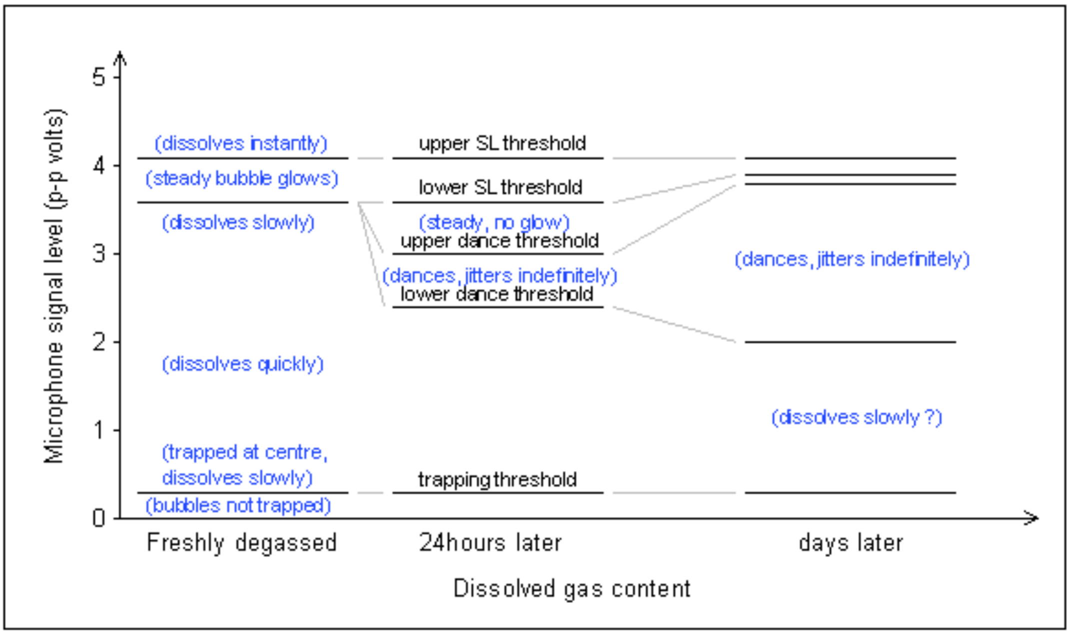

Figure 6. W.A. Steer's "Dependence of bubble characteristics on sound intensity and dissolved gas content." (Steer 9)

In order to view the bubble the room must be dark except for a small torch (flashlight) used to see the flask. Insert a bubble with the signal at resonance. If the bubble does not stabilize, try tuning down just below resonance and making sure that only a few bubbles are being made in the flask. The colder the water the brighter the glow will be so putting ice next to your flask to cool allows it to stabilize more easily.

When the bubble implodes, the blue light will flash continuously for around thirty seconds and then if you increase the amplitude it will disappear.

Results

Even though resonance was found, I did not observe sonoluminescence. At one point the flask did appear to glow but did not flash repetitively as has been recorded by other experimenters. The frequency range that this occurred at was 46.897KHz±0.0285KHz and the voltage recorded by the microphone PZT was 1.25V±0.2V. It is shown in Fig. 6 that this voltage is not high enough for sonoluminescence so it must have been a mistake. The voltage measured from the function generator when this occurred was 12.5V±0.2V, and the voltage from the amplifier was 7.5V±0.2V. Despite the fact that the voltage measured by the amplifier was lower than that of the function generator, when the experiment was carried out without the amplifier, the microphone only measured 0.85V±0.2V at resonance. In order for sonoluminescence to occur, a higher voltage is needed.

Reasons for error

Finding acoustic resonance was relatively simple; the main issues I found were with finding the electrical resonance and stabilizing the bubble.

Since I did not have a variable inductor, I needed to add inductors in series in order to increase the inductance. It would have been much easier to build an inductor around an iron rod by making coils of wire specifically for the inductance required. If this is possible I recommend this method.

The required inductance proved to be much higher than originally thought and no spikes in amplitude were found at the expected inductance. This was found to be because the PZT's given capacitance was an average of the range of capacitances they can exhibit. The changed capacitance meant that the expected inductance was also a range so since the capacitance exhibited was smaller than previously thought, the inductance was higher.

Stabilizing the bubble also proved difficult. I forgot that degassed water was hugely influential on the ability of the bubble to stabilize. Some experimenters found that boiling the water more than once prevented gas from dissolving back into the water so quickly.

It was also important to learn to solder properly before soldering wire onto your PZTs. Some PZTs were destroyed when the solder was too hot and the PZTs reached their Curie point. You can tell that a PZT has been destroyed if the oscilloscope shows that no current is flowing through it.

Conclusion

I had a lot of trouble achieving sonoluminescence. The main problem was finding electrical resonance and then keeping it, as the function generator I used was not very stable. Steer states that the function generator he used was tunable to within 30Hz at 25KHz and could stay there for a minimum of ten minutes. The one that I used could stay stable within 0.5KHz for ten minutes. It is strongly recommended that either a variable inductor (20mH-35mH varying by 1mH), or an inductor built to the required inductance be used, as finding resonance by adding inductors in series was very frustrating. At the moment resonance has been found but I am yet to observe sonoluminescence but I will keep making adjustments to the experiment until I do.

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