

ADVANCED UNDERGRADUATE LABORATORY

EXPERIMENT 11

Sonoluminescence

Revised: October 2004 by Jason Harlow

Based on material from www.teachspin.com

Sonoluminescence

Introduction



Sonoluminescence is the production of light from sound. This effect, discovered just over ten years ago, has been, and continues to be, the subject of considerable experimental and theoretical research.

Sonoluminescence (SL) refers to the phenomena in which a micron size gas bubble is both spatially trapped and oscillated by an acoustic field in such a way that on each compression of the bubble a small burst of light is emitted. This light emission is in the form of extremely short bursts ($< 100\text{ps}$), but is periodic, occurring in phase with each and every cycle of the driving pressure field. Each bubble collapse produces about 500,000 photons.

The bubble collapse is so violent that some predicted theoretical accelerations are larger than those associated with a Black Hole! The actual emission mechanism has not yet been explained, although theories are as plentiful as they are diverse.

Students begin their exploration by first understanding some basic acoustical principles, such as resonance behavior, quality factors, variation of sound speed with temperature, and the eigenmode structure of a 3-dimensional resonance "cavity." Once these principles are understood there are a large number of experiments that can be performed focusing on the liquid sample preparation and the light emitted from the bubble.

The basic apparatus, shown above, consists of a rectangular cell that houses the water with a high frequency piezo microphone, an ultrasonic horn that is used to deliver acoustical energy to the system, and a control box that contains an integrated amplifier and resonance detection circuitry. The control box also contains active components that can filter and rectify the signals from either the cell's transducer or from the separate high frequency hydrophone probe.

Among the other features in the control box are two separate adjustable power supplies, one for an optional temperature controlled cell and another for an optional photomultiplier, as well as a peak detector for the photomultiplier unit.

The Sonoluminescence experiments that can be carried out with the SL100B cover a broad range, but can be classified into two general categories: acoustical and optical. The acoustic experiments do not necessarily involve trapping a bubble, but rather explore the general acoustic properties of the cell and the liquid samples. The second type of experiments are all related to characterizing the light emitted from the bubble.

Equipment List

Controller

- Horn Output 30 VAC, DC-100kHz, 3A max
- Function Gen. Input 1 VAC into 10 kilohms
- Filter Cutoff 150 kHz (highpass)
- Peak Detector Time Constant 0.1s
- PMT Input Impedance 10 kilohms
- PMT Peak Detector Time Constant 0.1s
- Case Size 5 3/8" × 12 3/4" × 15"

Cell

- Rectangular Cell (Plastic) 2 1/4" × 2 1/4" × 5"
- Mode [1,1,3] at 27,000 Hz
- Pill Transducer: Type C5400 disc
- Freq. Resp. 1 kHz - 2 MHz, Sen. 1 V/ATM
- Mounting Caes with stand 5" × 6" × 10"
- Cylindrical Cells available

Horn

- Acoustic Power 50 W
- Max Input 1500 V
- Transducer Array 6 Element Stack
- Input Connector TNC

Accessories

- **Signal Generator**
 - Ramsey SG-550 Frequency Synthesizer
 - Range DC to 60kHz
 - Selectivity 1,10,100,1000,10kHz
 - Precision and Stability ±1Hz
 - Output: Sine 1Vp; Square 5Vp
 - Display 5 digits
- **Photomultiplier (PMT)**
 - Hamamatsu (side on)
 - Rise Time 2ns (into 50 ohms)
 - Supply Voltage 0-8 VDC
- **Hydrophone**
 - Frequency Response > 1 MHz
 - Sensitivity (approx.) 0.1V/ATM
 - Cable 4 feet RG174 BNC
- **Mounted Cylindrical Cell**
- **Mounted Cylindrical Cell with Peltier Temperature Control**
 - Cylindrical Cell
 - Cooling Power 50W
 - Supply 0-12 VDC @ 5A (max)
 - Bi-directional (heating or cooling)
 - Internal fan 40CFM

Activity Suggestions

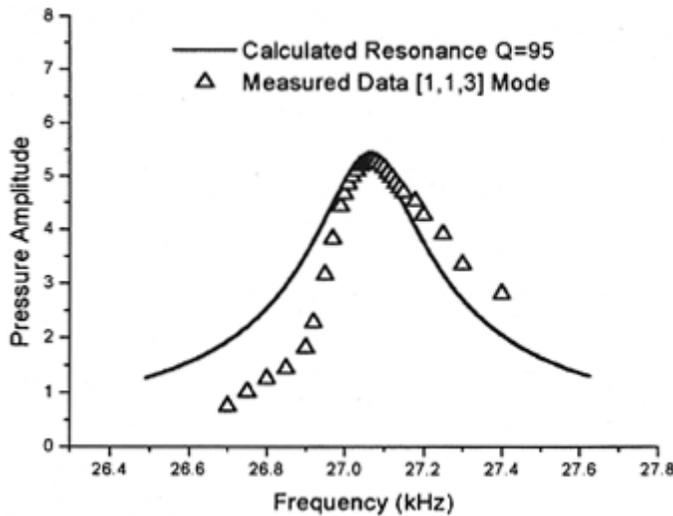
Acoustic Experiments

One of the most important topics in classical mechanics is the study of resonant phenomena and the solution to the wave equation in 3-dimensions, subject to specific boundary conditions. The acoustic wave equation, with its appropriate solutions provides fertile ground for exploring the many facets of a 3-dimensional system.

For the rectangular cross-section cell the eigenfrequencies in which the bubbles are trapped are given by:

$$f = \frac{v}{2\pi} \left[\left(\frac{n_x \pi}{L_x} \right)^2 + \left(\frac{n_y \pi}{L_y} \right)^2 + \left(\frac{n_z \pi}{L_z} \right)^2 \right]^{1/2}$$

where L_x, L_y and L_z are the length, width and height of the water filled cell and v is the velocity of sound in water. The hydrophone provides the student with an appropriate probe to verify the mode structure of the pressure field. That is, it allows the student to locate the pressure maximums and minimums of the water filled cell. Students can also make various perturbations to the cell geometry and investigate the phenomena of adiabatic invariance.

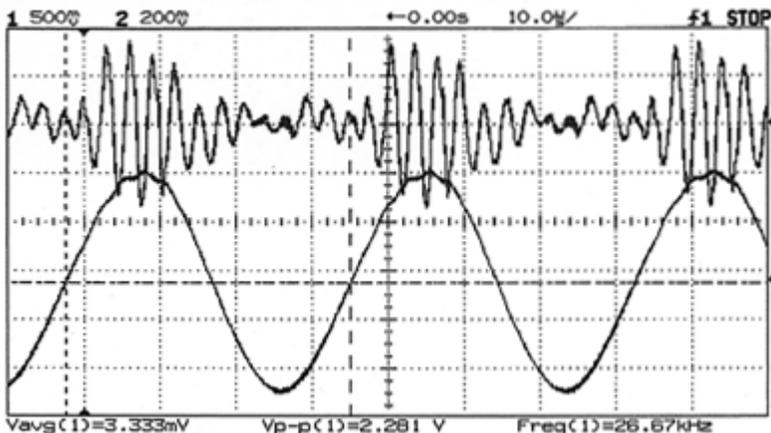


TeachSpin can also provide a cylindrical cell for these experiments. The analysis of the eigen modes for this geometry involves the mathematics of Bessel functions. The experimental techniques to verify the mathematical predictions are the same as those for the rectangular cell.

All resonant phenomena involve the storing of energy in the oscillating system. The quality factor, Q , of the system is the ratio of the energy stored to the energy dissipated during each cycle. The student can show that Q can be measured by studying the cell's acoustic amplitude response as a function of the driving frequency. The theoretical curve for the amplitude of a

driven, damped, simple harmonic oscillator as a function of frequency, along with real student data for a SL100B rectangular cell, are shown to the right.

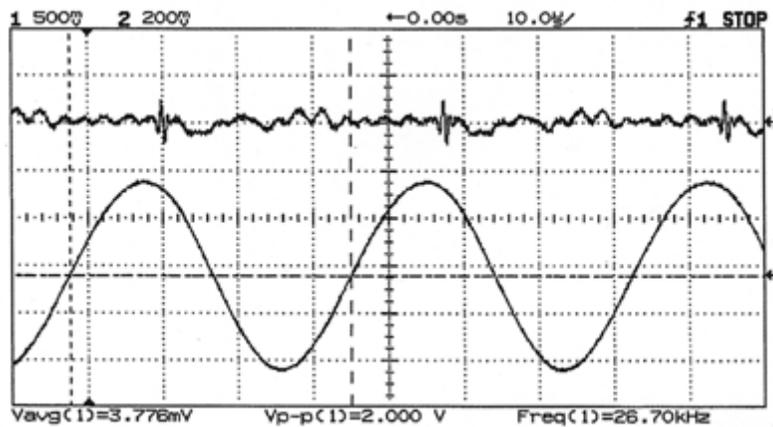
The quality factor Q may also be determined by abruptly terminating the input signal to the control box and observing the characteristic exponential decay of the cell's acoustic amplitude response.



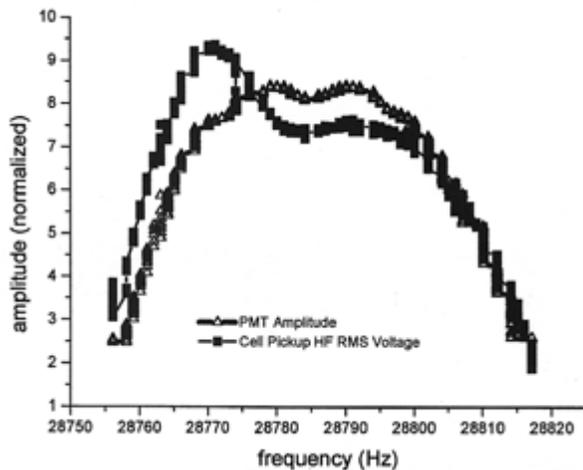
Optical Experiments

The variety of experiments that can be performed on the optical aspects of Sonoluminescence is limited only by the student's imagination and time. The experimenter's first task is to trap the bubbles at a sonic pressure node. The SL100B electronics give the student unambiguous signals characteristic of a trapped bubble.

To the right are the signals from the cell's transducer pill when there is no trapped bubble. The upper trace is the pill's signal as it appears from the filtered high frequency output. (The small high frequency "glitch" that appears on the upper trace near the maximum of the pill's signal is an artifact of the Ramsey signal generator)



The next data set shows the case when a gas bubble has been trapped. Note the signature acoustic signal from the collapsing bubble that appears on the upper trace. This is also observable, although less obvious, on the lower trace. The trapped bubbles were created by a short burst of current through a submerged heater. This causes local boiling around the heater. The bubbles migrate from the heater until they are trapped at one of the acoustic pressure nodes. The acoustic amplitude and frequency are adjusted to maximize the bubble trapping.



A series of experiments that can be performed quantitatively, with the addition of a photomultiplier tube PMT (sold as an accessory), involve correlating the light output with drive level, frequency, and temperature.

Another series of experiments that can be performed with the addition of a good quality oscilloscope, is setting an upper limit on the time duration of the SL flash. The student will be amazed to learn that the flash duration from the SL bubble is in fact many times smaller than the rise times of all but the most expensive PMTs. Measuring this simple property of the system can be accomplished with a generic PMT and an oscilloscope of sufficiently high bandwidth. The phase

sensitivity near resonance can be explored by observing the phase of the light emission relative to the driving frequency as the system passes through resonance.

Another useful measurement is that of the light intensity as a function of driving amplitude. By connecting the PMT into the peak detector, a DC voltage is generated which can be read with any voltmeter. This voltage is proportional to the peak voltage generated by the PMT. Measuring these characteristics will also enable the first time user of a PMT to gain a general understanding of a PMT's operational characteristics such as rise time, recover time and dark counts.

The last figure shows actual student data taken with a PMT and an AC voltmeter. The driving frequency is changed, passing the system through the mechanical resonance of the cell. As can be seen on the graph there is a close correlation between the light output and the amplitude of the high frequency acoustic signal emitted by the bubble just after its collapse.