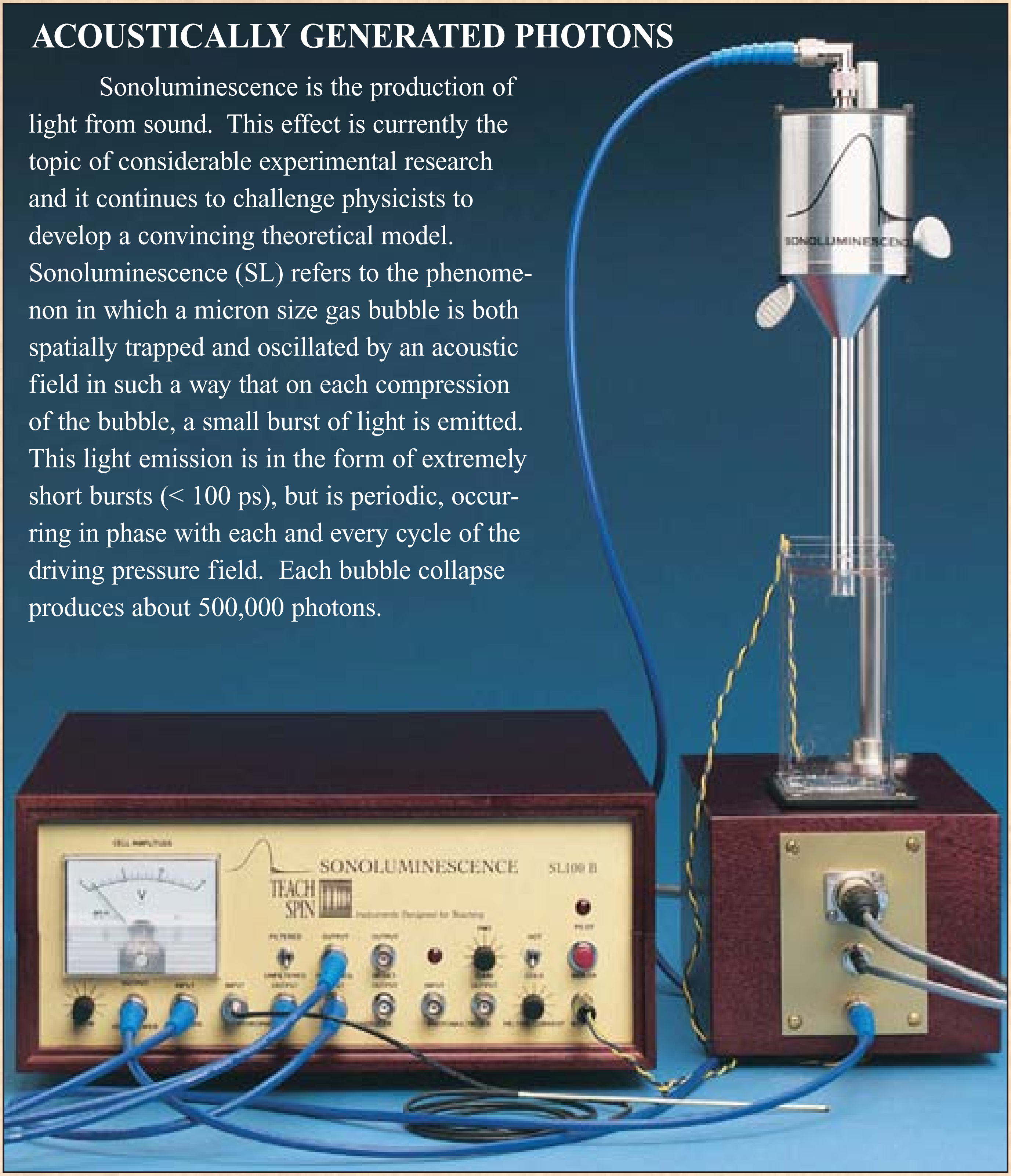
SONOLUMINESCENCE

ACOUSTICALLY GENERATED PHOTONS

Sonoluminescence is the production of light from sound. This effect is currently the topic of considerable experimental research and it continues to challenge physicists to develop a convincing theoretical model. Sonoluminescence (SL) refers to the phenomenon 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 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.



Instruments Designed For Teaching

TEACH SPIN

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 INSTRUMENT

The basic apparatus, shown on the front cover, 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 input.

EXPERIMENTS

The 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.

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 crossection cell the eigen frequencies 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, 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 phonomena 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.

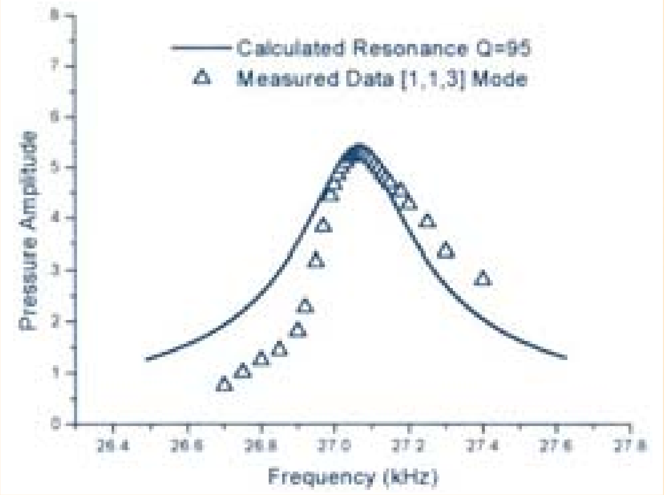


Figure 1: Pressure Amplitude vs. Frequency for a Rectangular Cell

All resonant phenomena involve the storing of energy in the oscillating system. The quality factor, or Q, of the system is the ratio of the energy stored to the energy dissipated during each cycle.

The student can show that the 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 in Fig. 1.

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. Below, in Figure 2, are the signals from the cell's transducer pill when there is no trapped bubble.

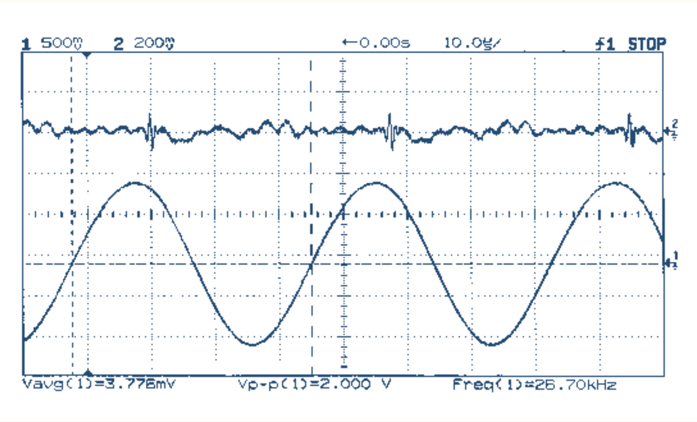


Figure 2: Transducer Signals with no Trapped Bubbles

The upper trace is the pill's signal as it appears from the filtered high frequency output. (The small high frequency "glich" that appears on the upper trace near the maximum of the pill's signal is an artifact of the Ramsey signal generator)

Figure 3 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 the 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.

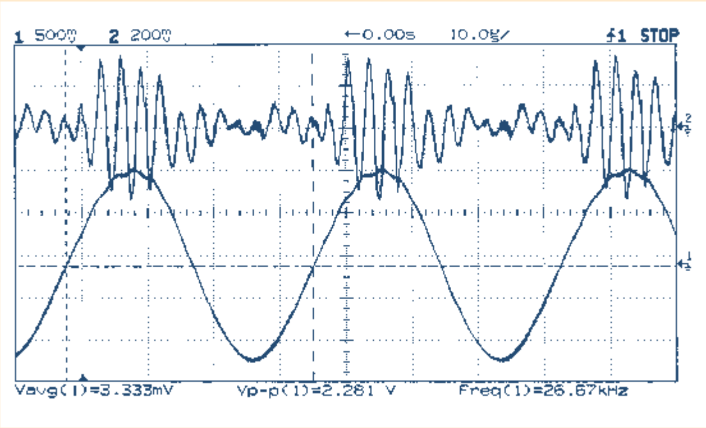


Figure 3: Transducer Signals with Trapped Bubbles

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 PMT's. 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.

Figure 4 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. 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 as can be seen from the data plotted in Figure 4.

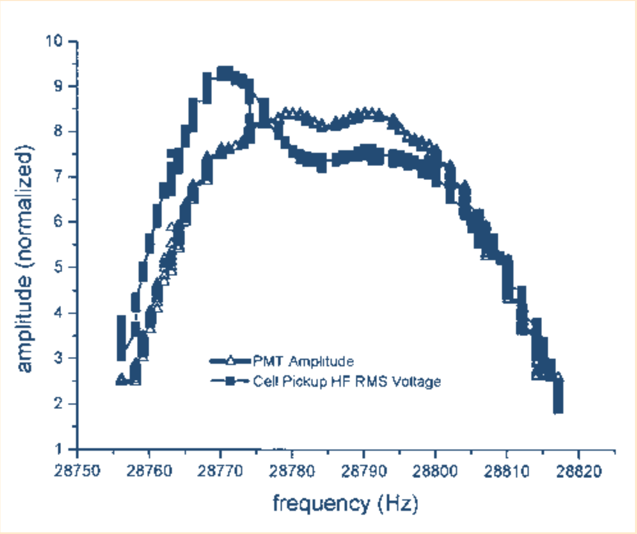


Figure 4: PMT Amplitude and Cell Pickup Voltage vs. Bubble Signal Frequenct.

The temperature dependence of the SL flash can be best explored using the Peltier Cooler Module, Figure 5. This cylindrical cell has a base that is thermoelectrically cooled and temperature controlled. It can maintain a temperature just above freezing for a long period of time.

Figure 5: Peltier Cooler Module

ACCESSORIES

A. Frequency Synthesizer
   Ramsey SG-560
   Range: DC to 5 MHz
   Frequency Steps: 0.1 Hz
   Accuracy: ±15 ppm
   Output: sine, square, triangle

B. Temperature Controlled Cell
   Peltier Cooling Power: 50 W
   Bi-Directional (Heating-Cooling)
   Cylindrical Cell: 3" Inner Diameter

C. Photomultiplier (PMT)
   Hamamatsu Supply and Tube
   Rise Time: 2 ns (into 50Ω)
   Supply Voltage: 0 – 8 VDC

D. Additional Cylindrical Cell

SPECIFICATIONS

CONTROLLER
   Horn Output: 30 VAC, DC-100kΩ, 3 A max.
   Function Gen. Input: 1 VAC into 10kΩ
   Filter Cutoff: 150 kHz (high-pass)
   Peak Detector Time Constant: 0.1s
   PMT Input Impedance: 10kΩΩ
   PMT Peak Detector Time Constant: 0.1s
   Case Size: 5 ⅜"x12 ¾"x15" Cell

CELL
   Rectangular Cell: Plastic, 2 ¼" x 2 ¼" x 5"
   Mode: [1,1,3] at 27,000Hz
   Pill Transducer: Type C5400 disc
   Freq. Resp.: 1kHz - 2MHz, Sen. 1 V/ATM
   Mounting Case with stand 5" x 6" x 10"

HORN
   Acoustic Power: 50 W
   Max. Input: 1,500 V
   Transducer Array: 6 Element Stack
   Input Connector: TNC

Hydrophone Probe
   Frequency Response: > 1 MHz
   Approx. Sensitivity: 0.1 V/ATM
Degassing Flask: 500 ml Pyrex with stopper and value

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