Volume 6

Article 14

2004

Investigation of Single Bubble Sonoluminescence by Acoustic Cavitations of D_20

Suzanna Williams
Georgia College

James Black
Georgia College

Curtis Harris
Georgia College

Ralph H. France III
Georgia College

Investigation of Single Bubble Sonoluminescence by Acoustic Cavitations of D_2O

Suzanna Williams
James Black
Curtis Harris
Ralph H. France III

Dr. Ralph H. France III
Faculty Sponsor

Abstract

The acoustic cavitation of D_2O is measured using an ocean optics ultraviolet spectrometer. Walls of a container were constructed for the D_2O using 2mm thick by 6 cm long quartz cylindrical cavity. The upper and lower transducers are silver plated piezoelectric quartz crystals. Compressing a Teflon seal between the piezoelectric crystal and quartz tube creates a watertight seal. Argon is bubbled through the solution of D_2O to replace any other existing dissolved gases, as single bubble sonoluminescence is known to work best with dissolved noble gases. The container is immersed in the D_2O and sealed using a cap. A standing wave in the cavity causes cavitations of the fluid which captures a seeded bubble of argon. Once the bubble collapses, the emitted light spectrum is measured using an Ocean Optics ultraviolet spectrometer. By measuring the emitted light spectrum a close approximation of the actual temperature can be obtained. However, as water is opaque to ultraviolet light, this may provide only a lower limit. If the temperature is high enough (approximately a few million K), fusion neutrons may be emitted, which will be measured in a future experiment planned to take place in collaboration with Yale University.

Introduction

Sonoluminescence is the transduction of sound energy into light energy, mediated through the presence of bubbles within the liquid supporting the sound field.[1] This simply means that as sound waves are pumped into the bubbles, the bubbles collapse and a continuous range of wavelengths of light are emitted. There are two basic sources of light emission. First light may be produced by quantum energy transitions and second by heat or blackbody radiation.[2] The light that will be emitted from the bubbles is expected to be from blackbody radiation. R. P. Taleyarkhan, et al. proposed that nuclear fusion exists via the cavitation of a bubble in D_2O.[3] It was determined from a literature search that the best possible method for producing nuclear fusion from sonoluminescence is single bubble sonoluminescence.[4] The goal of this experiment is to construct an Apfel single bubble sonoluminescence resonator to verify the results of R. P. Taleyarkhan.[5]

Single Bubble Sonoluminescence

Sonoluminescence involves a medium that may contain multi bubbles[6]; however, the main concern of this paper will be single bubble sonoluminescence. Single bubble sonoluminescence occurs at the pressure antinode of a standing wave in water.[6] In the middle of this standing wave, a small (100 microns) bubble is formed that will collapse at every oscillation of the standing wave. Upon collapse, high temperatures (~30,000 K) are achievable inside the bubble[7] This experiment consists of studying acoustic cavitation by using an ocean optics ultraviolet-visible (UV-Vis) spectrometer and later concluding whether theorized neutrons actually are emitted. An Apfel resonator4 will be used to cavitate a bubble in a solution of D_2O. In a solution of D_2O there exists a wide variety of dissolved gases from the air that can interfere with the experiment. It is necessary to remove all of these gases so that the experiment will be a success. Since argon is close to a perfect gas and almost completely inert, it will be sparged into the liquid in order to displace the other extant gases. A standing wave in the cavity will produce resonance. When argon gas is seeded into the solution of D_2O, the bubble will be captured by the standing wave. As the bubble collapses, light is emitted. This light spectrum can be measured via the UV-Vis spectrometer in order to obtain a close approximation of the actual temperature inside the bubble. Deuterated water, D_2O, is opaque to ultraviolet light so the temperature measurement may only provide a lower limit. If the temperature is high enough (~few MK), fusion neutrons may be emitted, which can later be detected by the Yale Neutron Ball in a future experiment.

Blackbody Spectrum

Blackbody radiation is a source of light that gives a continuous range of wavelengths. An example of a good source of blackbody radiation is the sun. If a spectrophotometer is directed at the sun, it is easy to see the broad bands of color that would come through the instrument. The blackbody spectrum of the sun can be fit to a 5780K curve on a graph of radiation intensity as a function of wavelength. Wien's law demonstrates that the maximum of this curve is in the visible spectrum

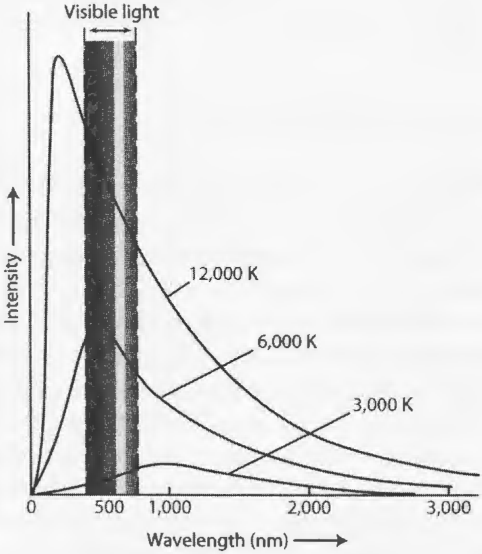

Figure 1

Figure adapted from Comins and Kaufman[8]

(Figure 1). From left to right, the bands represent: blue, blue green, green, yellow, orange, and red. The light that is given off from this experiment is from blackbody radiation and therefore is expected to fit a blackbody spectrum (Figure 1). As the temperature increases the spectrum will shift the peak intensity to the shorter wavelengths.

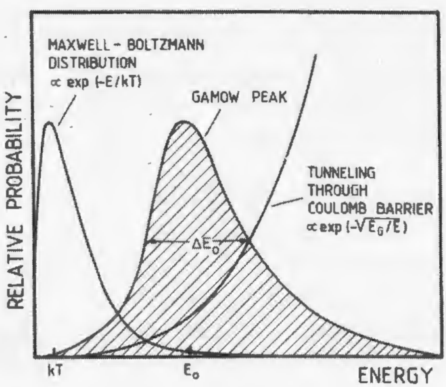

Figure 2

Adapted from Rolfs & Rodney[9]

The Gamow peak is the convolution of the deuteron Maxwell-Boltzman distribution and the columbic barrier giving the most probable energy for a molecule to tunnel through (Figure 2). The Maxwell-Boltzman distribution shows the probability distribution of the kinetic energy of the molecule. As the temperature increases, the tail of the peak will shift farther to the longer wavelengths. The further the tail of the peak shifts to longer wavelengths, the greater the probability of fusion. The Gamow peak shows the most probable energy for fusion.

Nuclear Reactions

When D_2O is placed in the cylindrical cavity there are two nuclear reactions that can occur:

$$(50\%) \qquad {}^{2}H + {}^{2}H \rightarrow {}^{3}H + p$$

$$(50\%) \qquad {}^{2}H + {}^{2}H \rightarrow {}^{3}He + n$$

The neutral deuterium atoms are from the D_2O in the cell. As shown in the above equations there is an equal probability of the reaction occurring in each reaction path. Equation 1 is not measurable in this experiment because all of the products are charged particles, ${}^{3}H + p+$, which are quickly stopped in the D_2O. Equation 2 has one charged particle ${}^{3}He$, which stops in the D_2O, and one uncharged particle, the neutron, which may pass through the heavy water and be detected.

Neutron Detectors

As mentioned above, neutron detectors (Figure 4) are a crucial part of the experiment. Each of the detectors was constructed at Yale University in 1989-1990.[3] They are made of liquid scintillator contained by aluminum cans, located in the bottom of the detectors pictured below.

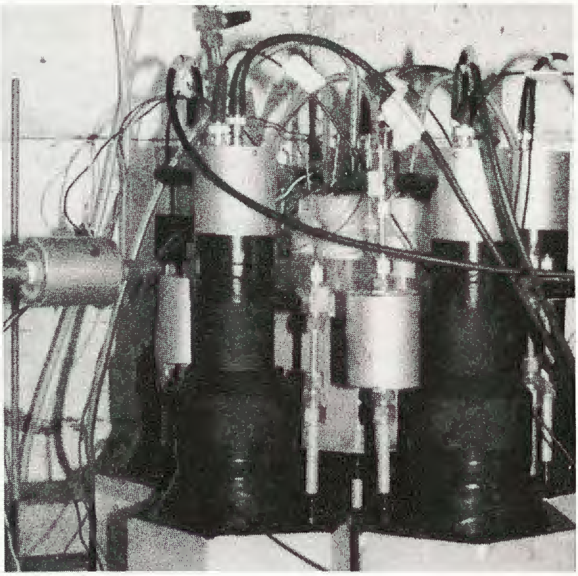

Figure 4

The solution in the cans is a liquid scintillator, NE213, a solution of naphthalene dissolved in xylene. The detectors are hit by two particles, a photon and a neutron. The photon knocks out an electron when it interacts with the NE213 while the neutron knocks out a proton when it interacts. The proton is almost 2000 times heavier than the electron and therefore produces a slower speed as well as a slower pulse of light. The PMT converts the light pulse into an electronic pulse, and the pulse shape discriminator is used to distinguish between proton and electron events (Figure 5). The peak on the left is a gamma ray peak made by the electronic pulse of the electron and the peak on the right is a neutron peak. The gamma ray peak is much higher due to the highly reactive charged gamma particle and low probability of a neutron reacting (Figure 3).

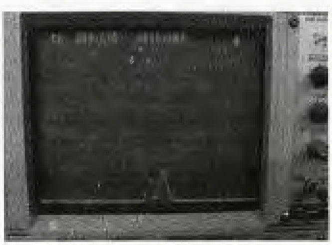

Figure 3

Since two different peaks are obtained from the emission of gamma particles and neutrons, a figure of merit can be applied to the peaks versus peak width.[3]

Bubble Dynamics

The bubble is collapsing at a frequency of approximately 25kHz, in which every other wave node will induce the collapse of the bubble (Figure 4).

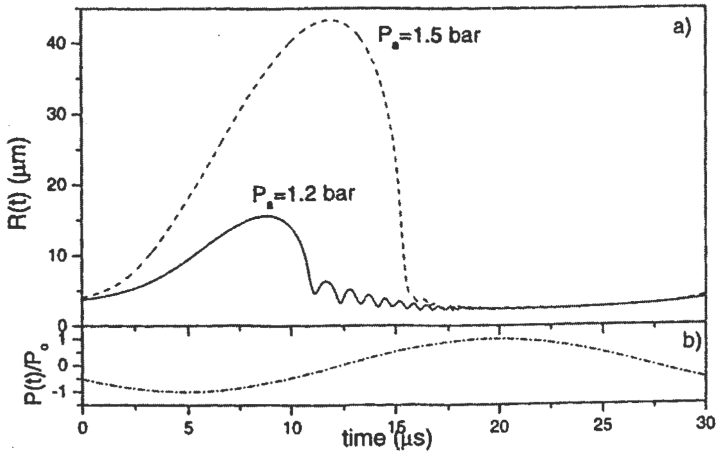

Figure 4

Adapted from Ketterling[4]

The bubble's radius continues to expand as the wave goes through an antinode and just as the bubble reaches its maximum radius it collapses in a time frame of approximately a few picoseconds. Upon the collapse of the bubble an intense flash of light is produced. The bubble's radius versus time peak can be modeled using Ketterling's equation (equation 4) derived from the Rayliegh-Plesset equation (equation 3). In these equations p is the density, r is the radius, r is the first derivative in respect to time, r is the second derivative of the radius, is the pressure next to the bubble, p.. is the pressure at some infinite point in space away from the bubble, v is the viscosity, o is the surface tension, Cw is the speed of sounds in water, H is the minimum diameter of the bubble, y is the polytropic constant, and P_{gas} is defined in equation 5.

$$\frac{1}{2}\rho\int_{R}^{\infty} 4\pi r^2 \dot{r}^2 dr = \int_{R_i}^{R} (p_1 - p_\infty) 4\pi R^2 dR$$

$$R\ddot{R} + \frac{3}{2}\dot{R}^2 = \frac{1}{\rho}(P_{gas}(R,t) - P(t) - P_0) - 4\nu\frac{\dot{R}}{R} - \frac{2\sigma}{R} + \frac{R}{\rho c_w}\frac{d}{dt}(P_{gas}(R,t) - P(t))$$

$$P_{gas}(R,t) = (P_0 + \frac{2\sigma}{R_0})\left(\frac{R_0^3 - h^3}{R^3 - h^3}\right)^\gamma$$

Apfel Resonator

We are in the process of constructing a new Apfel resonator (Figure 5)[4].

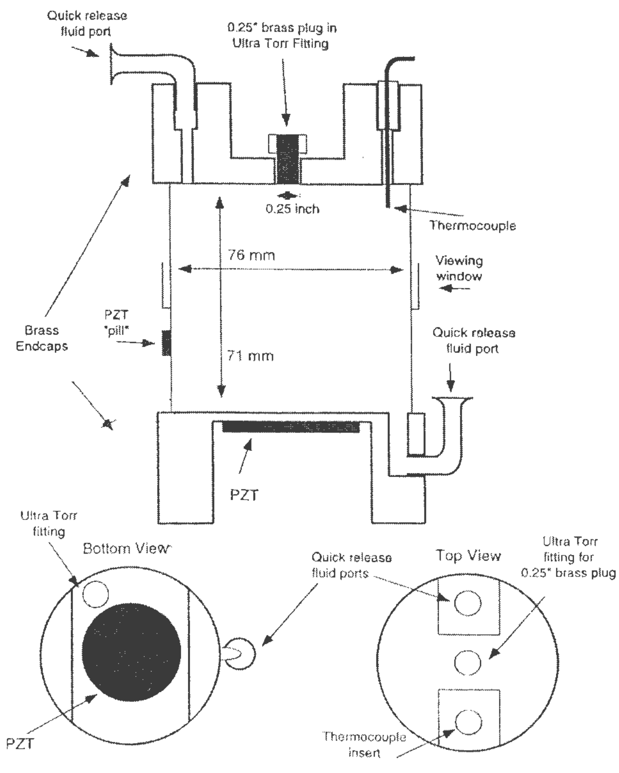

Figure 5
Figure provided by Ketterling (private communication)

Once the resonator has been constructed it will then be used to verify Ketterling's results in light water. In the experiment that is performed using light water (H_2O) no nuclear reaction occurs, and therefore, no neutrons are emitted. Once it is verified that the apparatus is working correctly, heavy water (D_2O) will be used to search for the nuclear reactions.

Conclusion

The best method for the production of single bubble sonoluminescence and for the theoretical production of neutrons was concluded to be an Apfel resonator. The currently proposed re-design for the experiment is shown below (Figure 6).

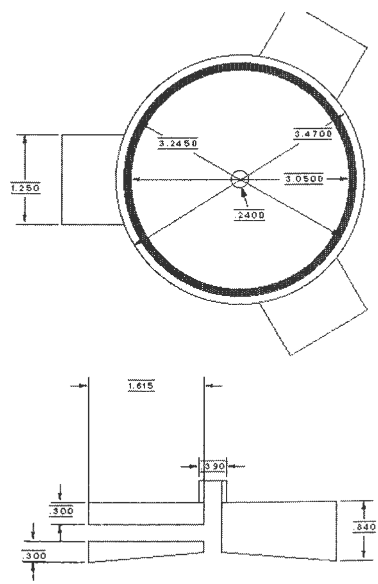

Figure 6

This design was made to allow for better seeding of the bubble and to prevent the collection of gas within the resonant cavity thus changing the resonant frequency. After the results are duplicated for heavy water, it will then be necessary to optimize the apparatus for the maximum temperature of the luminescence, as the final goal of the experiment is to maximize and measure the multiplication energy of the luminescence. Most of the research will be performed at GC&SU, with the neutron measurements to take place at Yale University.

Footnotes

1. Crum, Lawrence A. "Sonochemistry and Sonoluminescence"; Ed. Timothy J. Mason Ed. Jacques L. Reisse Ed. And Kenneth S. Suslick Ed. Kluwer Academic Publishers: Boston, 1999.

2. Physical Chemistry; Atkins, Peter Ed. And Julio de Paula Ed. W.H. Freeman and Company: New York, 7th Edition, 2002.

3. Rugari, S.L. et. al. "Upper Limits on emission of neutrons from Ti in pressurized D2 gas cells: A test of evidence for 'cold fusion'". Physics Review C (43)1298, 1991

4. Ketterling, Jeffery A. "An Experimental Validation of the Dissociation Hypothesis for Sonoluminescence and an Extension to the Analysis of Multiple Frequency Drives"; Thesis; Yale University, Hartford, Ct, 1999.

5. R.P. Taleyarkhan "Evidence for Nuclear Emissions During Acoustic Cavitation". Science; March 8 2002, v295, p1868-1873.

6. Crum, Lawerence A. "Physics Today". 1994, 9, 22-29.

7. Fundamentals of Physics; Halliday, David Ed., Robert Resnick Ed., Jearl Walker Ed. John Wiley and Sons, Inc. New York, 5th Edition, 1997.

8. Comins, Neil, Kaufmann, William III. "Discovering the Universe" 6th Edition. W.H. Freeman and Company, New York, 2002.

9. Rolfs, Claus E., Rodney, Williams S., "Cauldrons in the Cosmos". University of Chicago Press, 1988.