Multi-Bubble Sonoluminescence: How a Bubble Converts Sound into Light and Creates Spots as Hot as the Sun

William B. McNamara III Final Seminar April 6, 2000

Fields of cavitating bubbles are generated when a liquid is irradiated with high intensity ultrasound.[1] The collapse of these bubbles subjects the bubble contents to extreme temperatures and pressures that lead to both sonochemistry and the emission of light: multi-bubble sonoluminescence (MBSL).[2] Though there exists a substantial body of theoretical work on acoustic cavitation,[3,4] the intrabubble conditions and the mechanism by which these conditions are reached have not to date been unambiguously determined.

We set out to use MBSL, particularly metal atom emission generated by the sonication of solutions of metal carbonyls in silicone oil and low-volatility organic liquids,[5] as a probe of the conditions within an imploding cavitation bubble. This mandated that the emission must first be shown to arise unequivocally from the gas phase of the bubble. High-resolution MBSL spectra reveal that the atomic emission lines are broadened and blue shifted under helium relative their line-shape under argon. This is consistent with reports from other high-pressure studies,[6] indicating that MBSL is in fact emitted from the gas phase of the bubble.

We next developed a methodology that is capable of determining the temperature of sonoluminescence under a wide range of conditions.[7] Emission from metal atoms has long been used to measure the temperatures of flames[8] and plasmas,[9] as the spectra are sensitive to the temperature at which the atoms emit. We adapted this technique to MBSL and find that Fe, Mo, and Cr emission resulting from the sonolysis of the parent carbonyls in silicone oil all occur at 4800 ± 500 K : calculated and observed emission spectra are shown in Figure 1a and 1b, respectively.

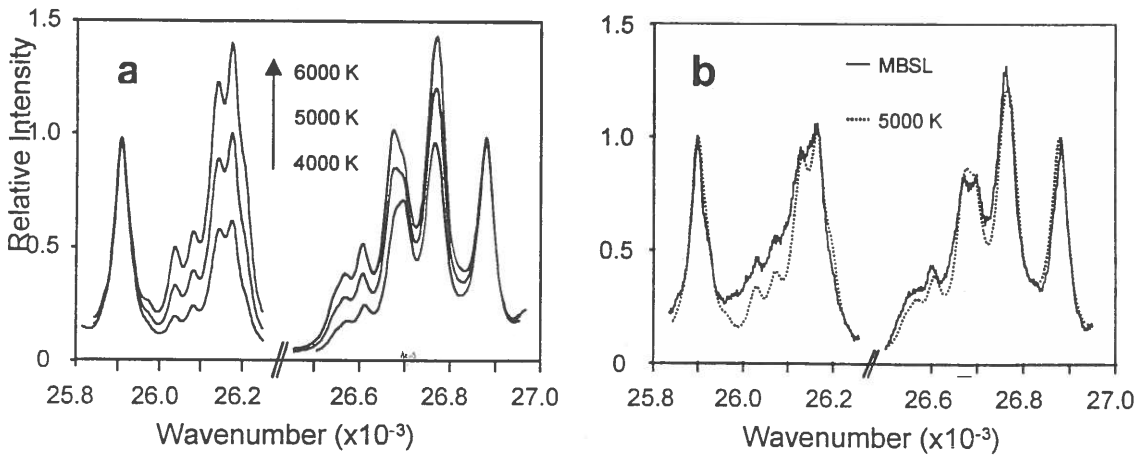
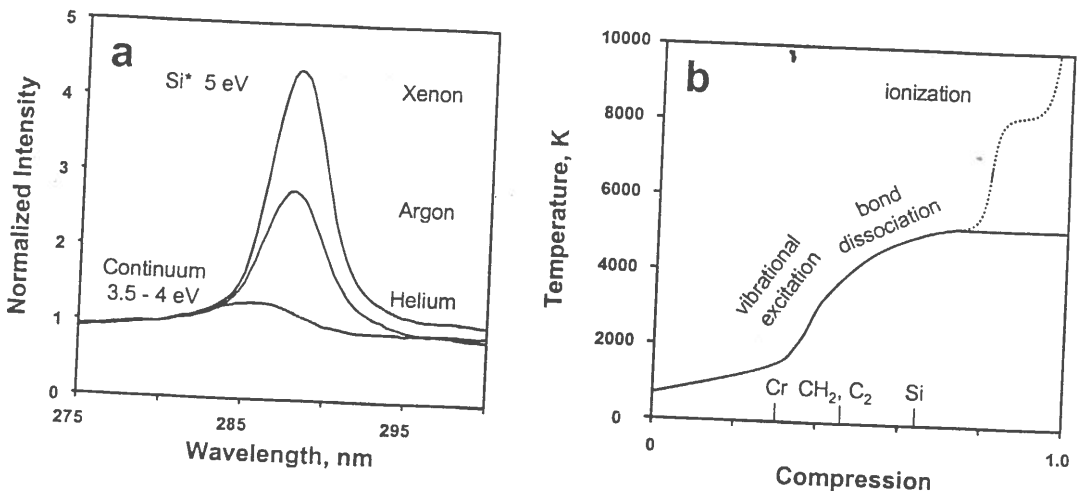


Figure 1

The mechanism of sonoluminescence and cavitational heating was studied by varying the polytropic ratio of the bubble contents. The introduction of polyatomic gases to the bubble, either as a gas or as solvent vapor, leads to a decrease in the temperature of sonoluminescence.[7] This decrease is consistent with the compressional heating model of cavitation.[10] Furthermore, the temperature is much more sensitive to solvent vapor than to small gaseous hydrocarbons, which we attribute to the importance of intrabubble chemistry. This hypothesis is strongly supported by the behavior of the metal atom emission with respect to the underlying continuum, which indicates that the continuum is molecular in origin rather than plasma emission. The experimentally determined distinction between a continuum arising from molecular emission rather than plasma emission is particularly relevant in light of the recent discovery of single bubble sonoluminescence,[11] which is believed to involve temperatures on the close order of 20,000 K.[12]

While the temperature of MBSL was shown to depend strongly on the polytropic ratio of the bubble contents, it proved to be remarkably insensitive to changes in its thermal conductivity,[13] in stark contrast with theoretical predictions.[3] In keeping with previous studies, however, we find that the intensity of MBSL increases by nearly two orders of magnitude as the thermal conductivity is decreased in the order of He, Ar, and Xe. This change in intensity is accompanied by changes in the relative intensity of different emitting species. As seen in Figure 2a, low levels of energy deposition in the bubble (under the very thermally conductive He) lead to spectra dominated by emission from low energy species, while the spectra under Xe (corresponding to a substantially greater amount of work done on the bubble) are dominated by emission from higher energy species.



The results outlined above led to the development of a model that stresses not only the temporal evolution of the temperature within the bubble, but also the evolution of different species within the bubble. This is schematically illustrated in Figure 2b. The compressional heating during bubble collapse leads to entropy-driven chemistry. The weak metal carbonyl bonds are broken early in the collapse, and subsequent collapse leads to the dissociation of solvent vapor. These processes consume a sizable fraction of the bubble's potential energy and essentially constitute an upper limit to the temperature attainable during bubble collapse. These results are of particular importance to the field of cavitation, where research has

concentrated on the physics of bubble dynamics and either ignored intrabubble chemistry or treated it as a perturbation.

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