Experiments on Sonoluminescence: Possible Nuclear and QED Aspects and Optical Applications

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Abstract. Experiments aimed at testing some hypothesis about the nature of Single Bubble Sonoluminescence are discussed. A possibility to search for micro-traces of thermonuclear neutrons is analyzed, with the aid of original low-background neutron counter operating under conditions of the deep shielding from Cosmic and other sources of background. Besides, some signatures of QED-contribution to the light emission in SBSL are under the consideration, as well as new approaches to probe a temperature inside the bubble. An applied-physics portion of the program is presented also, in which an attention is being paid to single- and a few-pulse light sources on the basis of SBSL.

INTRODUCTION

A lack of a complete explanation of some unusual characteristics of sonoluminescence came to be a source of a few exotic suggestions about its nature. For our studies we selected the most intriguing ones that are somehow in line with a general scientific stream in Dubna research center. Search for predicted nuclear and quantum electrodynamic effects in sonoluminescence is an aim of described experiments that are now in a stage of preparation.

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EXPERIMENTAL APPROACHES

*Hot-plasma hypotesis.* It was predicted that very high temperatures are possible at the moment of a collapse of the sonoluminescing bubble. Under some special mode of upscaling sonoluminescence (a strong short pressure pulse should be added to the ultrasound standing wave) the temperature presumably reach a level of observable traces of thermonuclear fusion in the D+D system. The additional short pressure pulse with a magnitude of several bars are to be synchronous with the sonoluminescence flash. If the system contains deuterium dissolved in heavy water (D$_2$O) a neutron yield is expected. A value about 0.1 nph is predicted for some optimal conditions [1]. Measurements of this low neutron rate are planned to be done by means of a triple-coincidence method using an original neutron counter. The neutron spectrometer was designed taking into account requirements for minimizing the γ-ray and random coincidence backgrounds [2]. It is a calorimeter based on a liquid organic scintillator-thermalizer with $^3$He proportional counters of thermalized neutrons distributed uniformly over the volume. The energy of thermalized neutrons is transformed into light signals in a scintillation detector. The signals from proportional counters provide a ‘neutron label’ of an event. The triple coincidences are to be sorted by a following algorithm:

$$( \text{signal from the sonoluminescence-light flash} ) \& ( \text{the scintillator flash in moderator} ) \& ( \text{the signal from the } ^3\text{He counter} ).$$

The measurements are supposed to be performed in the underground laboratory of the Baksan Neutrino Observatory of the Institute for Nuclear Research of Russian Academy of Sciences, Caucasus. A shield from cosmic rays in this Lab is about 5,000 m of w.e. Under these conditions a sensitivity of about 0.01 nph can be reached for about a three-month measurement cycle. The main components of necessary devices and equipment are already in our disposal, including the sonoluminescence devices and the neutron counter.

The system of intensive pressure pulsing is under construction. Certainly, many efforts are necessary to modify the experimental setup and accommodate it for the measurements at Baksan. To reach the most possible sensitivity in these experiments it would be reasonable to use a so-called few-bubble-sonoluminescence (FBSL) regime when several single bubbles are trapped within a higher harmonic modes of acoustic resonator as it was reported in [3]. We have observed concurrently lighting SL-bubbles in the second harmonic under some special boundary conditions which have yet to be specified [4].

*QED-hypotesis.* Another idea connects the sonoluminescence to the energy of zero vibrations of the vacuum (Casimir energy) [5]. To test this idea the following two types of experiments are designed.

1) *Transforming a short wave part of the sonoluminescence spectrum to the region of $\lambda$ higher than the water absorption edge.* To this end, certain specific luminofores should be selected, and among them perhaps tiny dispersive powder of crystal röntgenoluminofores would be promising as an interaction with lattice is essential in this case. Certainly, possible influence of those suspensions on cavitation properties of water have to be clarified beforehand. If the hypothesis on the
vacuum-fluctuation nature of the sonoluminescence phenomenon is valid then no short wave emission with $\lambda < 200\,\text{nm}$ is expected.

(2) Angular-correlation measurements of the coincident photons in the vicinity of $180^\circ$. The QED model for the sonoluminescence predicts the emission of time-correlated pairs of photons flying away in opposite directions.

Some other experiments are considered also. In particular,

(1) Direct testing the so-called dissociation hypothesis (DH) of the sonoluminescence. According to DH, when the stable single bubble sonoluminescence conditions have been created, the inert gas alone remains inside the bubble. Due to high temperature inside the bubble all other components (nitrogen and oxygen) undergo the intensive chemical interaction with each other and with water. This results in nitrogen oxides (NO, NO$_2$) and NH$_3$ [6]. At present only indirect evidence for the DH has been found [7,8]. For direct measurement of the products of dissociation a small SL cell, completely closed to the atmosphere, and containing a relatively small volume of water, will be needed. Long-time runs can be accomplished via computer-controlled monitoring of the system [9].

(2) Measurements of spatial distribution of the light in water. Measurements of the time-averaged spectral distribution of the radiation emitted by the bubble will be done in the presence of the luminofore additives that will be used in the procedure of spectrum-trasformation experiments. The aim of the experiments is to infer the source brightness in the short UV range by means of taking into account the diffusion of UV emission in the water solutions or suspensions of the above luminofores, and, by comparing them with predictions of quasi-stationary thermal source model, estimates of plasma temperature are expected to be obtained [10].

(3) Study of near-IR spectrum of the emission of Xe-doped bubble. We will try to search for spectral lines of Xe similar to distinctive line emissions observed in high pressure xenon lamps.

**DEVELOPMENT OF NEW TYPE OF SUPER FAST PULSE LIGHT SOURCES**

One of the most remarkable features of SBSL flashes is their brief duration. The most recent measurements show that many parameters, such as the nature and concentration of gases, temperature, pressure, resonance performances of the SL instrument, etc., influence the temporal and other properties. For example, larger flasks operating at lower frequencies, cause the bubble to emit more light [11]. It is important that the light pulse duration remains the same within the limit of a few picosecond for whole wavelength range.

Goals of this part of experiments are:

(1) Studying parameters controlling the duration of light pulses and other temporal parameters of SBSL radiation. (2) Investigation of correlation in intensity of flashes. In this experiment the statistical properties of the intensity of the light
flashes will be studied to determine the short-term and long-term aspects of SL. The synchronicity between flashes has been shown to be remarkably high [12]. It is interesting whether the intensity distribution is as narrow, as well. (3) Development of SL-light sources of single light pulses. To this end the Kerr cells will be applied. Regular and relatively rare repetition of the flashes makes possible using the photo-shutters with a limited temporal resolution to obtain the single pulses with temporal performances determined by primary SBSL-properties. (4) Development of methods to generate various series of the single light pulses. (5) On this basis, developing simple, inexpensive light sources for physical research, fist of all for the time-resolution calibration of fast photodetectors (PMT and the like).

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