Detecting sound wave of bubbles produced in a boiling liquid

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Abstract

This experiment attempted to detect the sound wave produced by bubbles in boiling water and liquid nitrogen as an application for LUX, large underground xenon, which is expected to detect weakly interacting massive particles, WIMPs. Currently, there are still several steps needed to be done in order to detect the bubble waveform. Before proceeding any further, it is necessary to change the current setup by using a device that will boil water without producing noise and that will release one bubble at a time. In this way, it will be easier to identify a bubble's waveform on the oscilloscope. Also, a microphone more sensitive than the piezo crystals may be needed to detect bubbles produced from a boiling liquid. Otherwise, a smaller vessel may help increase the piezo microphones' sensitivity to the changes within the vessel. Once an appropriate microphone has been found that will detect bubbles from boiling water, liquid nitrogen should be used to better emulate the conditions found in LUX.

Introduction

Dark matter has been of interest since Fritz Zwicky first observed galaxies in the Coma cluster moving at a much faster rate than what was expected. He proposed that there must be another form of matter present in the universe [1].

Astronomical observations, such as gravitational lensing, velocity curves of spiral galaxies, and velocity dispersion among galaxies, have led scientists to believe that all known matter occupies less than 4% of the universe and that over 96% is invisible matter, which interacts weakly with the rest of known matter [2].

One candidate for dark matter is the WIMP, weakly interacting massive particle. Several experiments have been done to narrow down the possible mass of WIMPs, in which liquid xenon has been used. Through the collisions of WIMPs and xenon nuclei, ionization and scintillation is produced. Xenon10 is one of the experiments in which a dual phase response was used to indicate whether or not WIMPs interacted with the liquid xenon.

The basic design of Xenon10 (Figure 1) is a dual phase time projection chamber of 15 kg in which xenon is present in both the liquid and gas phase.

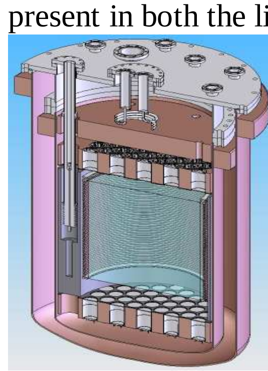


Figure 1: Xenon10 diagram

The scintillation from the nuclear recoil is captured by the photomultiplier tubes (PMTs) at the top and bottom of the metal chamber, and is labeled as the primary response (S1). The scattered electrons also produced from the nuclear recoil are drifted to the top by an electric field and accelerated through the xenon gas producing a second scintillation, which is indicated as the secondary response (S2). The logarithm of the ratio of these two responses, S2/S1, indicates whether the reaction was caused by a WIMP or background events, such as gamma radiation or neutron interactions (Figure2). Due to xenon's self-shielding properties, background events can be eliminated by only considering events occurring towards the center of the liquid xenon. For this reason a fiducial mass of 5.4 kg was used for data collection. After rejecting background events, the data from Xenon10 indicated that ten out of 1800 events occurred in the expected WIMP window in 58.6 days [3].

Currently, LUX is the next development in the WIMP search. LUX, large underground xenon, will be similar to Xenon10, except the fiducial mass will be increased to 100 kg and it will run for 300 days allowing for a greater possibility of WIMP interactions. In order to eliminate cosmic microwave background radiation, LUX will be located 4850 ft below ground in the Davis Cavern, which is under the Sanford Laboratory in South Dakota. A ~6m water cherenkov shield will surround LUX in order to eliminate gamma radiation. Neutron interactions, which will primarily be from the PMTs, will be rejected due to xenon's self-shielding [4].

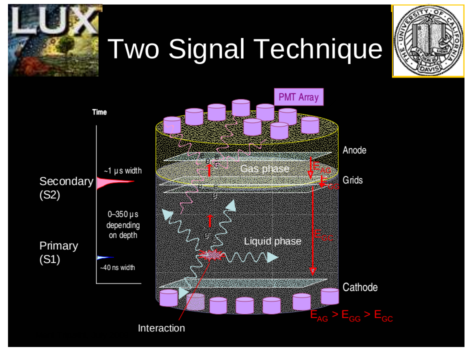


Figure 2: Primary response produced by scintillation and secondary response are the scattered electrons.

Due to the rise in temperature near the PMTs, it is expected that LXe will transition into the gas phase causing bubbles to drift to the surface. It is unclear how the presence of bubbles will affect LUX results. The main concern is that the scattered electrons will be lost or delayed, which will affect the secondary response. If the expected gamma-like curve for background events is corrupted due to bubbles, it could place the results in the WIMP window.

In order to explain any unexpected results due to bubbles, two methods will be used to detect them. As used in Xenon10, there will be two parallel plates at the surface of the LXe (Figure 3), which will indicate changes in the volume level by measuring the capacitance. The second method that is being considered is to place microphones on the outside of the LXe chamber in order to listen for drifting bubbles.

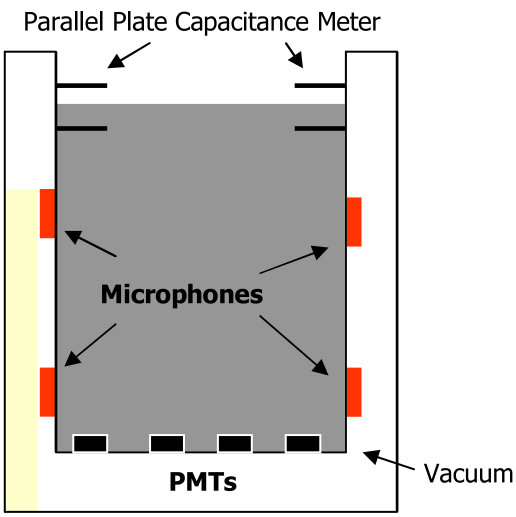


Figure 3: Microphones located on side of inner tank (in vacuum) and capacitors placed on surface of LXe.

Technical Background

It is expected that the expansion and collapse of the bubbles will be heard in the range above 20 kHz. For this reason, a piezo amplifier (Figure 4) was used as a high frequency microphone in this experiment. This device operates using piezoelectricity, in which the sound wave caused by a bubble will compress the piezo crystal, which then produces a voltage change across the disc; this voltage difference is then read on an oscilloscope.

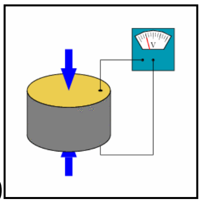
a)  b) 

Figure 4: a) Piezo crystal. b) When compressed by sound, the crystal produces a voltage across disc.

Since the microphones will be placed on the titanium chamber of LUX, a steel container was used to conduct this experiment. In addition to being similar to the metallic properties of LUX, the metal container (Figure 10) also reduces the amount of sound lost. Initially, this experiment was performed in a glass tank. However, glass does not hold sound well, so it was replaced by metal.

Figure 10

To produce bubbles similar to those expected to form in LUX, water was used as the medium to produce bubbles. Using a DC power supply, ten amperes were run through a coiled nichrome wire to heat the water to a boil.

Results

Currently, the waveform of a bubble formed from a heated liquid has not been detected. There are still several steps needed to be done in order to detect these bubbles.

Initially, the piezo crystals were picking up noise from the DC power supply when heating and boiling the water. This was apparent since this particular noise occurred only when the power supply was turned on and stopped when it was turned off. In order to eliminate this noise, the metal container, which also included the attached microphones, the DC power supply, and the oscilloscope were grounded. This seemed to effectively remove this interference.

When boiling the water, a continuous stream of small bubbles were produced. However, it was necessary to create one bubble at a time in order to effectively detect its waveform on the oscilloscope. In order to gather the small bubbles being produced and create larger single bubbles, a metal cone (Figure 11) was placed over the nichrome wire.

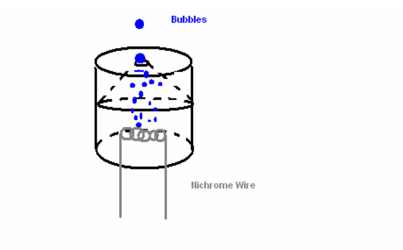


Figure 11: The metal cone gathers smaller bubbles and produces one larger bubble at a time.

This successfully produced one to three bubbles at a time within approximately ten seconds apart from each other. However, at the time this was done, the DC power supply had not been grounded and was interfering with any possible noise from the bubbles. Another problem that occurred was that the cone itself was heating up and producing small bubbles on its surface. Also, due to a corrosive substance being produced from the nichrome wire, the cone's inner surface deteriorated and could no longer produce single bubbles.

In order to create similar bubbles that are expected to be produced in the liquid xenon, liquid nitrogen was experimented on since it has similar properties to xenon. However, too many bubbles were being produced at once because the vessel was not properly insulated. In order for this experiment to work, the liquid nitrogen would need to be contained in a controlled environment below its boiling point, 77 K, and be slightly heated to produce one or two bubbles at a time.

While conducting this experiment, noise was being produced from the environment. In order to remove vibrations being transmitted from the table on which the vessel was on, the metal container was placed on a foam base. This seemed to decrease the noise produced from tapping or touching the table. There was also noise from outside of the room being picked up, such as doors being closed. A cardboard box with foam lining was placed over the vessel in order to remove this background noise. However, this did not seem to make a difference and was removed from the experiment. Another method used to isolate the container and microphones was to place another larger metal chamber over the smaller one in which the experiment was being done in. It appeared this effectively isolated the experiment from background noises. However, by creating a space between the inner vessel and the outside environment, sound was echoing in this secondary air chamber and interfering with the sound being produced from the inner vessel.

Since a metal container was being used, there was some concern that sound produced from the bubbles was echoing within the vessel and interfering with the initial sound wave. It was decided that the sound produced from the bubbles would be the initial response and the ringing that followed (Figure 12) was most likely an echo within the vessel and could be ignored.

Throughout the experiment, the piezo crystals were used as microphones due to their high frequency range. However, these devices may not be sensitive enough to pick up the sound of bubbles that are formed in a heated liquid. To test the crystals, a plastic tube was used to blow bubbles in the water. The microphones seemed to detect single bubbles drifting to the surface. However, when using the nichrome wire to create bubbles from boiling water, there was no sound detected from a stream of slightly smaller bubbles. This may indicate that the piezo crystals are not sensitive in the expected frequency range. It is also possible that sound is being lost due to the metal container. A smaller vessel may be needed to conduct this experiment with these particular microphones. Also, these piezo crystals have a natural resonate frequency of ~5 kHz (Figure 12). However, it's unclear whether or not this is affecting the results.

Figure 12: Two piezo crystals of slightly different sizes were used for coincidence. As seen above, both crystals produced same sound wave, with the smaller one (yellow/upper) producing smaller oscillations of ~5 kHz.

Conclusion

Before proceeding further in this experiment, it is necessary to change the current setup by using a device that will boil water without producing noise and that will release one bubble at a time. In this way, it will be easier to identify a bubble's wave form on the oscilloscope. Also, a microphone more sensitive than the piezo crystals may be needed to detect bubbles produced from a boiling liquid. Otherwise, a smaller vessel may help increase the piezo microphones' sensitivity to the changes within the vessel. Once an appropriate microphone has been found that will detect bubbles from boiling water, liquid nitrogen should be used to better emulate the conditions found in LUX.

References

[1] Gates, E. Einstein's telescope: the hunt for dark matter and dark energy in the universe. New York: WW Norton & Company; 2009. 305 p.

[2] UC Davis. Large Underground Xenon Experiment (2008), http://www.physics.ucdavis.edu/svoboda/lux/experiment.html

[3] Angle, J., et al. First results from the xenon10 dark matter experiment at the Gran Sasso National Laboatory (2007), arXiv:0706.0039v2 [astro-ph].

[4] Tripathi, M. LUX: Large Underground Xenon Experiment, Presentation (2009).