Phonon Detection in LXe, Specific Aims

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Abstract

In this report the capstone project idea is presented clearly along with a limited background research surrounding the topic. Further, the project objectives and deliverables are presented supported by appropriate literature review to justify their novelty, or difference in approach. Namely, the aim of the project is to design a detection methodology for particles in Liquid Xenon through the detection of phonons produced by the particle's interaction with a Xenon nucleus. The project is targeted into detecting Muons with the hope of expanding the detection range into smaller energy ranges in the future.

1. Background on Phonons

Heat or Sound are vibrations on the molecular level. When those vibrations are propagating in some way through a material in any phase we can think of them as wave packets that carry energies [10]. And much like quantum physics, we can think of those quanta of heat or sound through a material as particles that are propagating, merge, decay, etc. Those particles are called phonons (ϕ). Phonons are essential on dark matter research as they pose one of the ways by which we can detect perturbations in materials. Specifically, when some particle interaction deposits energy on the material of a detector, is often the case that this energy will be distributed as kinetic back to the system [11]. This molecular vibration will propagate through the material as phonons of different frequencies [11]. Phonons of higher frequencies quickly decay slow transverse (ST) phonons that can excite thermally, or mechanically a detector at the edge of the material [10].

2. Literature on Detecting Phonons

There are 2 different categories of detection methodologies as described by [12]:

- Thermal. Where the phonon is absorbed and thermal excitation is measured
- Athermal. Any other way for detecting a phonon, from mechanical induction to spectroscopy.

Some general methodologies for detecting phonons in different media are: Silicon/Germanium detectors [9, 7, 3], particle cascade detection in superheated liquids [1, 4], bubble chambers [5], placing nanothreads in liquid helium and detecting the rate of change of damping [8], single wavelength spectroscopy [6], and more.

Most of the aforementioned techniques are already in use in the search for dark matter with a high degree of success. However, as it is evident from the literature, most research is currently focused on the detection of phonons in cryogenic solids or superheated liquids.

3. Specific research project idea

The project proposed focuses on proposing a methodology for augmenting the capabilities of the XENONnT detector thorough the detection of produced phonons from nuclear recoil interactions with WIMPS. Specifically, for the purposes of the capstone project, the reasearch aim is refined in detecting phonons produced by the interaction of LXe nuclei with muons. The choice of muons was made since they are amongst the more massive elementary particles, and thus they can provide enough energy to produce a detectable amount of phonons. Therefore, the general research question can be formulated as such:

"What is the most appropriate methodology to detect phonons produced in liquid xenon due to nuclear recoils caused by muon interactions?"

4. Specific Aims

The specific deliverables and aims of the project are listed in more details below.

- Development of a numerical simulation for the production of phonons in Liquid Xenon due to muon interactions. Specifically, determine a model for the fraction of the produced energy from the muon LXe nucleus interaction that is converted to vibrational kinetic energy. Use phonon theory of liquids [2] to predict the decay and propagation patterns of the created particles in the liquid. Thus, determine the phonon flux per unit are on a possible detector.
- Determine the appropriate type of detector based on simulation results as well as other factors such as radioactivity, interference, resolution, etc. Choose between spectroscopy, mechanical athermal detectors, or thermal detector.
- Perform a small scale experiment to verify the simulation results.

- Compare the muon flux with output from other equipment i.e. muon telescope, etc. so that to ensure that the readings are accurate.

- Provide the theoretical framework and suggestions as to how the developed setup can be accommodated to detect the lower frequency phonons produced by WIMP nuclear recoils.

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