Aspects of Superheated Droplet Detectors and their application in Dark Matter Search

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Introduction

A superheated droplet detector (SDD) [1] consists of a large number of droplets of a superheated liquid suspended in another immiscible liquid-like, soft gel medium or a firm polymer matrix. The droplets are kept in the superheated liquid state at temperatures above the normal boiling temperature of the liquid (corresponding to the ambient pressure) by isobaric heating or isothermal decompression.

The basic principle of operation of SDD is similar to that of a bubble chamber. The superheated state being metastable, the passage of an energetic particle through a droplet can trigger a 'nucleation' event, whereby the energy deposited by the particle within the droplet can cause a phase transition of the metastable liquid phase to the vapour phase. If the energy deposited by the particle within a certain critical length is larger than a certain critical energy, the vapour bubble grows, eventually converting the whole liquid droplet into the vapour phase. The acoustic pulse generated in this process constitutes the signal of passage of the particle, which is recorded by acoustic sensors. SDDs are currently being used in various areas such as in neutron dosimetry, gamma ray detection, proton detection, heavy ion detection, neutron spectrometry and also in cold dark matter search experiments.

In the present work we shall focus on a detailed study of the response of SDDs to various kinds of particles such as neutrons, alpha particles, gamma rays and heavy ions, with a view to a better understanding of the working principles of SDDs in general and towards developing effective procedures for discrimination of nucleation events due to various particles (neutrons, alphas, gamma rays, etc.) that are known to be responsible for the background events in experiments for direct detection of Weakly Interacting Massive Particle (WIMP) candidates of dark matter (DM) using SDDs.

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Present work

The present study is divided into two parts: The main objectives of Part I are (i) to study the response of the SDD to heavy ions and, in particular, to study the dependence of the nucleation parameter (k) on the mass of the heavy ions, and (ii) to study discrimination of neutron and gamma-ray induced nucleation events in SDDs with different active liquids. In Part II, certain issues pertaining to the application of SDDs in the direct detection of the WIMP candidates of DM by the PICASSO experiment (Project In CAnada to Search for Supersymmetric Objects) [2] are discussed. Specifically, results of investigations into the following aspects of the experiment are presented: (i) To understand the reason behind the two different threshold temperatures observed for α-induced events in the detector, (ii) to study the role of the droplet size (of the active liquid) in the discrimination between α- and neutron induced nucleation events in the detector, and (iii) development of an analysis procedure to improve the resolution of discrimination between the α- and neutron (or nuclear recoil) induced events.

Result and discussion

The response of SDD to high energy heavy ions namely ^{12}C (180 MeV/u), ^{20}Ne (400 MeV/u) and ^{28}Si (350 MeV/u) has been studied with GEANT3.21 simulation toolkit to determine the values of the nucleation parameter, namely, k. Two sets of simulations have been performed - in one set the actual experimental set up has been simulated while in the other set instead of simulating whole set up, the bubble nucleation probability of a single droplet as a function of the nucleation parameter (k) is determined. From both of the simulations the normalized count rates at the threshold temperature of bubble nucleation are calculated and compared with the experimental data. The value of k for which the deviation between experiment and simulations is least is taken as best values of k for a particular ion. The present simulation provides that the nucleation parameter, (k) depends on the mass number of the ions.

In the next topic we focus on the discrimination of the neutron and gamma - ray induced nucleation events in SDD. We have performed experiments using two different liquids, namely, R-114 ($C_2Cl_2F_4$; b.p. 3.7°C) and C_4F_{10} (b.p. -1.7°C). For this purpose, we have used a ^{252}Cf (3.2 μCi) fission neutron source and a ^{137}Cs gamma-ray source (32.5 mCi). We have performed the experiments at the neutron sensitive temperatures of 55°C for R-114 and 35°C for C_4F_{10} and also at neutron and gamma-ray sensitive temperatures of 70°C for R-114 and 55°C for C_4F_{10} in presence of ^{252}Cf source. After analysing the experimental data it is observed that the discrimination between the neutron and gamma-ray induced nucleation events are possible by measuring the pulse height. It is also observed that R-114 as active liquid of SDD produces better discrimination than C_4F_{10}.

The Part II of the present study is related to understanding the alpha background of PICASSO detector and developing analysis method to increase the resolution of the discrimination between alpha and neutron induced nucleation events. First we performed a simulation to understand the two different threshold temperatures for two alpha sources, namely, ^{241}Am and ^{226}Ra. From the results of the simulation using GEANT3.21 simulation toolkit [3] and calculation of LET using SRIM 2008 software [4], it is observed that the threshold temperature is lower in the case of ^{226}Ra spiked detector (for which the α contamination is present both in the droplet as well as in the polymer matrix) than in the case of ^{241}Am spiked detector (for which the source of the α contamination is in the polymer matrix only) due to bubble nucleation caused by recoiling nucleus ^{210}Pb generated in the ^{226}Ra decay chain.

The effect of the droplet size on the discrimination between α- and neutron induced events, considering the low frequency components of the signal are studied by performing experiments with superheated R-12 (CCl_2F_2, b. p. -29.8 °C) droplets dispersed in soft aquasonic gel in presence of two neutron sources, namely, ^{241}Am-Be (3 Ci) and ^{252}Cf (3.2 μCi), and an α-source, ^{241}Am (30 particles s^{-1}) at the temperature of 33.5±0.5 °C. Instead of obtaining larger amplitude of pulses for alpha-particle induced events, as previously observed by COUPP, PICASSO and SIMPLE experiments, both smaller and larger amplitude pulses are observed in our present experiments due to the droplet size distribution used in our experiment.

The last topic is related to new data analysis technique to improve the alpha-neutron discrimination using PICASSO experiment data. This has resulted in an improvement of the resolution of the PVAR (which is a measure of the acoustic energy released during the bubble nucleation process) distribution for neutron calibration data of PICASSO experiment.

References

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