Simulation of the intrinsic background of PICASSO detector for dark matter search experiment

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Introduction

PICASSO (Project In Canada to Search for Supersymmetric Objects) at SNOLAB, is one of the experiments which search for cold dark matter through the direct detection of WIMPs via spin-dependent interactions with ^{19}F nuclei [1]. It uses superheated perfluorobutane, C_4F_{10}, as the target material. Since C_4F_{10} has b.p. -1.7°C at a pressure of 1.013 bar, droplets are in a moderately metastable superheated state at ambient pressure and temperature. PICASSO detector is the superheated droplet detector (SDD) consisting of a large number of droplets of superheated liquid suspended in another immiscible liquid like gel or polymer matrix. During the passage of a energetic particle through a drop, if the energy deposited in a certain critical length within the drop is larger than a certain critical energy, the superheated liquid undergoes a phase transition to vapour phase, *i.e.* a nucleation event occurs. Acoustic pulse generated in this process constitutes the signal, which is recorded by acoustic sensor. These droplets are sensitive to neutrons, charged particles, gamma rays etc under different operating conditions of temperatures and pressures [2,3]. For dark matter search experiment, the detector ingredients should be such that it minimizes the intrinsic background that coming out of the detector material. Alpha particles are the most dominant intrinsic background for this type of detector for PICASSO WIMPs search experiment. In the present work, the response of PICASSO detector to alpha particles is studied using GEANT3.21 simulation toolkit [4].

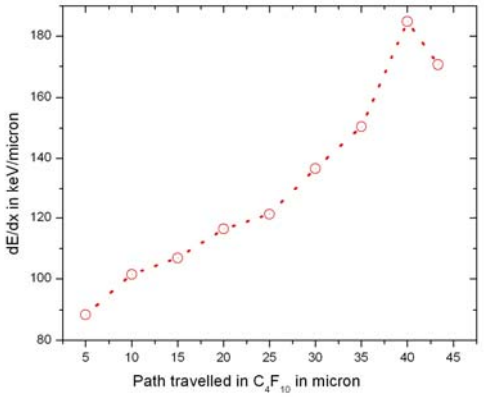
The aim of the present simulation is to study the response of the detector to α -particles coming from contamination of ^{241}Am in the detector ingredients and verify the results with the experiment. This is also our intension to find out the nucleation parameter (***k)*** [1] for α induced nucleation. The condition of bubble formation is that if the Linear Energy Transfer ($\frac{dE}{dx}$) by a particle is greater than critical energy deposition $\left(\frac{W}{kr_c}\right)$, nucleation occurs. Here W is the threshold energy at a particular temperature and pressure, r_c is the critical radius at a particular temperature and pressure, and ***k*** is the 'nucleation parameter'.

Present work

To begin the simulation, the range and stopping power of 5.6 MeV α-particles in C_4F_{10} of density 1.437 gm/cc is studied using GEANT 3.21. The simulation has two parts, geometry and tracking of particles. In the simulation, the energy deposition can be obtained after each 5 μm path. From the simulation, it is obtained that for 1.49 MeV energy, $\frac{dE}{dx}$ of α-particle have maximum value 184.73 keV/ μm. It is also obtained that the range of 5.6 MeV α-particles is about 43.33 μm and $\frac{dE}{dx}$ is 88.45 keV/μm. Result from the simulation is shown in Fig.1. The result is satisfactory to do the next simulations with GEANT3.21.

^{241}Am decays following the reaction, $^{241}Am \rightarrow {}^{237}Np + \alpha + 5.64MeV$. Contribution to bubble formation by ^{237}Np recoil is very small due to its short range and it stays in the polymer. So, in the simulation, nucleation due to recoiling ^{237}Np has not been considered. In this case, nucleation is only due to α-particles for which the nucleation parameter (k*)* needs to find out. The first part of the simulation is creating the

geometry of the detector and in this part, a holding matrix of CsCl of density 1.6 gm/cc and C_4F_{10} liquid is created.



Fi g. 1 $\frac{dE}{dx}$ vs depth for the α-particles.

Then a small prototype detector of CsCl having diameter 15 mm & height 80 mm is created. Volume loading fraction of C_4F_{10} is taken as 0.84%. So, 28350 non-overlapping droplets of C_4F_{10} are distributed randomly and uniformly within CsCl. The diameter of each drop is taken as 200 μm. The distribution of centers of the droplets has been done by using random number generator 'SRAND' code.

The next part of the simulation is the tracking of the particle. Simulation has done for experiment time duration of 1 hour. The detector volume is considered as 14.14 cc in the simulation, the activity of ^{241}Am is ~ 0.06 Bq. Total number of 216 α-particles with energy 5.64 MeV are distributed randomly and uniformly within only the polymer. Three components of α-particle's momentum have also been distributed randomly. Again, 'SRAND' random number generator is used for creation.

Discussion

From the simulation $\frac{dE}{dx}$ within a drop is obtained. If the $\frac{dE}{dx}$ is greater than $\frac{W}{kr_c}$, it is taken as 'nucleation event'. Extra events due to more than one nucleation from same drop are rejected in order to obtain the actual number of nucleation event.

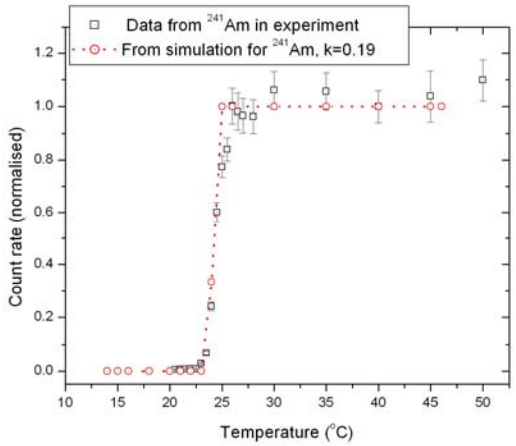


Fig. 2 Response of alpha particle from ^{241}Am

The count is normalized by the total experimental time duration and the active mass. In Fig.2, the simulation result [circles] is shown, where count rate is normalized to unity. The points obtained from simulation are joined by a red dotted line. Fig.2 shows that the simulation result matches to experimental result [squared] for nucleation parameter of 0.19.

The present simulation shows that the detector becomes sensitive to alpha contamination coming out of the gel matrix if any, at about 24°C. The WIMP sensitive region is in between 18°C to 40°C where the detector remains sensitive to alpha particles also. In PICASSO experiment, presently the R & D are going on to reduce the alpha contamination in the gel ingredients so that it would either lower the limit of the WIMP-nucleon cross section in the exclusion plot or to detect a WIMP signal.

References

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