The effective recoil nuclei in superheated droplet detector for WIMPs dark matter search

Mala Das* and Susnata Seth
Astroparticle Physics & Cosmology Division, Saha Institute of Nuclear Physics, Kolkata – 700064, INDIA
** email: mala.das@saha.ac.in*

Introduction

Superheated droplet detector is one of the useful detectors independently for cold dark matter (WIMPs ; Weakly Interacting Massive Particles) search experiments and for neutron detection under different operating conditions [1,2]. WIMP induced nuclear recoils are similar to neutron induced nuclear recoils and therefore have several identical techniques in detection. Hence, for WIMPs search experiment, the energy calibration is done with neutrons. Extensive studies have been made with R114 ($C_2Cl_2F_4$; b.p. 3.7°C) as the sensitive liquid for the response of neutrons and gamma rays for this type of detector [3]. C_4F_{10} (b.p. -1.7°C) is one of the most favoured sensitive liquids for cold dark matter search experiment as used by PICASSO (Project In CAnada to Search for Supersymmetric Objects) collaboration [2]. In the present work, we perform a comparative study between the two liquids, R114 and C_4F_{10} with respect to neutron detection in a mixed neutron – gamma radiation field, so that also for the WIMP-calibration studies. In order to explore the neutron response, the gamma sensitivities of C_4F_{10} detector have been studied. The dependence of the power spectrum of the neutron and gamma induced events on the recoil nuclei of the sensitive liquid has been explored.

Present work

The responses of self made C_4F_{10} and R114 superheated droplet detectors, were measured in presence of ^{252}Cf (3.2 μCi) fission neutron source by varying the temperature of the detector in the range of 35°C to 70°C. For further pulse analysis, the temperature was chosen 35°C, 55°C for C_4F_{10} and 55°C, 70°C for R114 detector. The volume of each of the detector was 40 ml in glass vial with aquasonic gel as the supporting matrix of the superheated droplets. The detector container was placed inside the water bath by controlling the temperature of the water with a temperature controller (Metravi, DTC-200) of precision ±1°C. The acoustic pulse formed due to bubble nucleation was measured by a condenser microphone with a frequency response expanding up to about 30kHz [14]. The traces of the electrical pulse output were recorded in dizital storage oscilloscope (Agilent Technologies, MSO7032A). The power, *P* which is a measure of the energy released during the bubble nucleation process, is defined as $\mathrm{Log}_{10}\left(\sum_i |V_i|^2\right)$ where V_i is the pulse amplitude in volt of the digitized acoustic pulse at the i^{th} time bin, and the summation extends over the duration of the signal [4].

For WIMPs and also for neutrons, the recoil nuclei are produced due to interaction with the detector liquid, and these recoil nuclei deposit their energy in the liquid according to their LET (linear energy transfer) in the medium. The energy deposition in the sensitive liquid was calculated using SRIM code for the carbon, fluorine ion in C_4F_{10} and for carbon, chlorine, fluorine ion in R114 for the neutron of maximum energy 6 MeV. The relation between the energy of the neutron and the operating temperature of the liquid can be obtained from basic condition of bubble formation with the LET of the effective recoil nuclei. The recoil nuclei with maximum LET in the liquid called the effective nuclei, plays the key role in the bubble formation process.

Results

The $\frac{dE}{dx}$ curves of different constituent nuclei in R114 and C_4F_{10} are shown in fig.1. The two horizontal lines (dashed and dashed-dotted) in fig.1 are the critical LETs for bubble nucleation in R114 at 55°C and in C_4F_{10} at 35°C, calculated using basic condition of bubble formation [5].

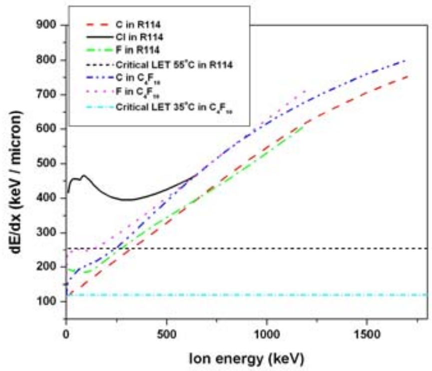

Fig.1. $\frac{dE}{dx}$ of C, Cl, F in R114 and C, F in C_4F_{10}.

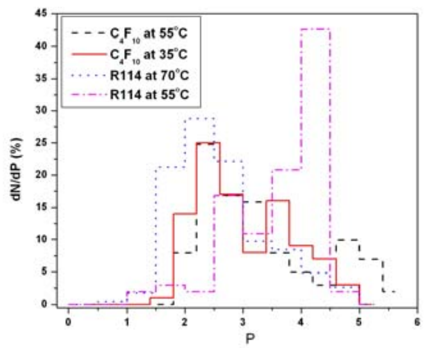

Fig.2. The differential power distributions at different temperatures for C_4F_{10} and R114 in presence of ^{252}Cf fission neutron source.

Discussions

In the present experiment, the threshold temperature (T_{th}) for gamma sensitivity of the C_4F_{10} detector fabricated in a normal (non-cleanroom) condition is found to be in the range of 45°C< T_{th} < 50°C. Therefore, studying the neutron sensitivity in the present work, we restrict to temperatures, 35°C well below 45°C. For R114 detector, gamma sensitivity has already been studied and was found to be sensitive above 65°C. In the present work, the gamma induced events of the detectors were measured at 55°C for C_4F_{10} and 70°C for R114. It is observed from fig.1 that $\frac{dE}{dx}$ of chlorine (effective nuclei) is much higher in the lower energy region than that of other recoil nuclei, namely carbon (C) and fluorine (F) in both the liquids. Since the peak energy of neutrons from ^{252}Cf fission neutron source occurs at about 700 keV, the maximum energies of recoil nuclei obtained from elastic head on collision with neutron are 74.6 keV, 198.8 keV, 133.0 keV for chlorine, carbon and fluorine respectively. In this connection, it is to be noted that the WIMP induced nuclear recoils are in the range of 1 – 100 keV. At these low recoil energy region, because of the high LET of chlorine, energy deposited within the effective length required for bubble nucleation at a given temperature is larger in R114 than those due to carbon and fluorine in C_4F_{10}. This large energy deposition is reflected in the measured power spectrum as shown in fig.2. Therefore, the discrimination of events caused by nuclear recoils and by gamma rays is more prominent in R114 than in C_4F_{10}. Fig.2 shows that for R114, neutron and gamma induced events are well separated, while for C_4F_{10} it is not. Superheated liquid having massive effective recoil nuclei provides better neutron – gamma discrimination. It is also clear from fig.2 that the P-distribution for gamma induced events for both the liquids, C_4F_{10} and R114, falls in the same region, independent of the composition of the liquid. The present observations provide useful information in calibration studies and background discrimination for WIMPs dark matter direct search experiment.

References

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