Measurement of threshold of superheated liquid detector for dark matter search

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Introduction

The existence of dark matter (DM) offers a good explanation for various astrophysical and cosmological phenomena, ranging from rotation of the galaxies to the large scale in-homogeneities in the cosmic microwave back-ground radiation. Weakly Interacting Massive Particles (WIMPs) are the most promising DM candidates. WIMPs are expected to interact with the detector nuclei via elastic scattering similar to neutrons, resulting in nuclear recoils. Direct detection of DM experiments are looking for the signature of nuclear recoils produced by WIMPs. The superheated liquid detector technology provides a promising approach to direct detection of DM search experiment. PICO is one of such dark matter search experiment running at SNOlab, Sudbury with bubble chamber containing superheated liquid as the target.

In addition to the high mass region, the future DM experiments are aiming to search for the signal in the low WIMP mass region also. For the investigation of low WIMP mass region (below 10 GeV/c^2), the target containing hydrogen nuclei is effective. In the lower WIMP mass region, the detector needs to be operated at lower threshold energy. The Superheated liquid detector is sensitive to gamma rays at lower threshold. Therefore, for the low mass WIMP run at lower threshold, the gamma sensitive temperature of the detector needs to be investigated.

In the present work R-134A ($C_2H_2F_4$, b.p.-26.3 ^{0}C) liquid has been chosen as active liquid in Superheated Droplet Detector. Experimental study has been performed to determine the gamma threshold temperature. The threshold energy for bubble nucleation at various temperatures has been calculated. The energy deposition inside the liquid has been calculated using SRIM code and the required ion energy for bubble nucleation at the various temperatures including the threshold has been estimated.

Principle of bubble nucleation

To form a bubble of critical radius R_c, the energy deposition (E_{dep}) by a charged particle along an effective path length (L_{eff}) within the superheated liquid must be greater than or equal to the critical energy (W). The critical energy is given by Gibbs' equation,

$$W = \frac{16\pi}{3} \frac{\sigma(T)^3}{(P\upsilon(T) - \mathrm{Po})^2} \qquad (1)$$

Here, $P\upsilon(T)$ is the equilibrium vapour pressure of the superheated liquid, Po is the ambient pressure, and $\sigma(T)$ is the surface tension at temperature T. The critical radius for the bubble formation is given by the following expression

$$Rc = \frac{2\sigma(T)}{(P\upsilon(T) - Po)} \qquad (2)$$

From bubble formation condition, the following expression can be obtained that relates the temperature of the detector to the energy of the incoming particle.

$$\frac{W}{kRc} = \frac{dE}{dx} \qquad (3)$$

Where, k is the nucleation parameter.

Present Work

In the present work, we have studied the response of R-134A detector to gamma rays from ^{137}Cs (1mCi) as a function of operating temperature. The superheated droplet detector has been fabricated at the laboratory and the droplet size as measured was found to be in the range of 30-70 micron. At the top of the detector, condenser microphone was placed, which converted the acoustic signals to the electric signals. By changing various temperatures, measurements have been done both in presence of ^{137}Cs source and for the backgrounds. The observed variation of number of bubbles nucleated per minute with the various temperature of the detector as obtained from the experiment is shown in Fig.1.

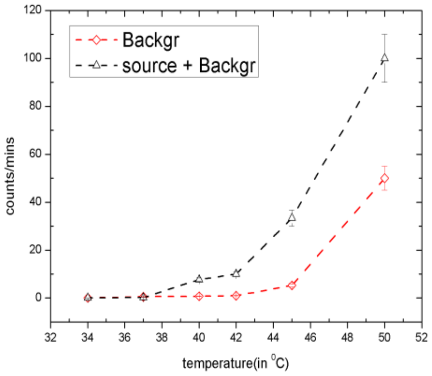

Fig. 1 Temperature verses count rate

In the above plot, the dotted line (black) shows count rate (/min) in presence of source and dotted lines (red) shows the count rate (/min) for background. From the plot, we observe that after 37 ^{0}C, the count rate started increasing. Therefore, it is observed that the detector becomes sensitive to gamma rays beyond 37 ^{0}C but not sensitive in lower temperature. It is also observed that the gamma sensitive temperature came near the mid-point between the boiling point and the critical temperature (101.06 ^{0}C) as mentioned in the literature [1].

The threshold energy for various temperatures was calculated using equation (1) which shows that as the temperature increases, the threshold energy decreases. At 37 ^{0}C, threshold energy as calculated is 0.042keV. We have calculated the stopping power of nuclei H, C, F in R-134A by using SRIM software which is shown in Fig.2. The required stopping power for bubble nucleation at various temperatures for different ions has also been calculated which is shown in Fig.3. For 37 ^{0}C, the required stopping power for bubble nucleation is 25.31keV/micron. For getting same linear energy transfer, ion energy is different for different nuclei. Ion energy for different nuclei as calculated is found out to be as H (10keV), C (0.1keV), F (0.06keV).

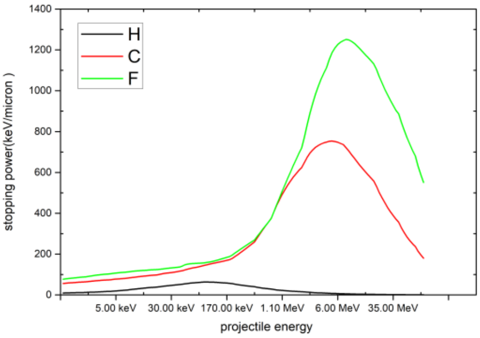

Fig. 2 Projectile energy verses Stopping Power

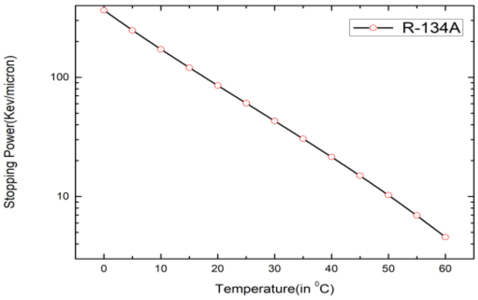

Fig. 3 Temperature verses Stopping Power

Conclusion

The present experiment and calculations provides the information on the characteristics of the active liquid R134A and detector response to the 662keV gamma rays. In the higher temperature region above 37^{0}C, detector is sensitive to gamma rays. Gamma rays act as a background for WIMP signal detection while operated as low as 42eV threshold at 37^{0}C corresponds to 10keV H-recoil. The experiment is going on to discriminate the gamma rays induced events from the nuclear recoils events.

References

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