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Threshold temperatures of heavy ion-induced nucleation in superheated emulsions

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Abstract

The threshold temperatures of nucleation in superheated emulsions were investigated with self-made superheated emulsions using R114 as sensitive liquid irradiated with a number of heavy ion species at several hundred megaelectron volt per nucleon. Calculations were made to estimate the threshold temperatures of nucleation for heavy ions of different energies. The calculation shows that the response of the emulsion increases near threshold temperature and then saturates to a value corresponding to the drop size of the superheated liquid. The nucleation rates were observed as a function of the operating temperature of the superheated emulsions for different heavy ion species and energies, and a comparison is made with the calculation.

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Keywords: Heavy ion; Superheated emulsion; Threshold temperature; Critical LET

1. Introduction

It has been established that superheated emulsions (the superheated drop detector [1] and the bubble detector [2]) are useful as neutron and gamma ray detectors [3,4]. Superheated emulsions have recently been applied to detect heavy ions; however, the literature on this topic is scarce [5–7]. Threshold value of Linear Energy Transfer ((LET): linear rate of energy transferred from the charged particles to the medium) of ions in superheated emulsions has been determined by irradiation with different heavy ions. It has been reported that different heavy ions can be identified by measuring the maximum track length of the ions in an emulsion [5–7]. The detection of light charged particles with superheated emulsions has been investigated by irradiation with protons with

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the detector axis parallel to the beam and by observing the bubbles along the tracks of the ions in the emulsions [4,8,9]. However, the experimental conditions have been limited to room temperature and experiments at higher temperatures are required for a better understanding of the response of superheated emulsions and in order to further develop these types of detectors.

The present work studies the nature of the response of the emulsions using R114 ($C_2Cl_2F_4$, boiling temperature, 3.77°C) as sensitive liquid to different heavy ions of different energies by varying the operating temperature of the emulsions and measures the threshold temperature of nucleation by heavy ions with self-made superheated emulsions. The superheated emulsions used in the present work consist of drops of superheated liquid suspended in a firm polymer matrix. The emulsions were irradiated with ^{12}C (180 and 230 MeV/u), ^{20}Ne(400 MeV/u), ^{28}Si(180 and 490 MeV/u), and ^{56}Fe(500 MeV/u). In the next section, response of superheated emulsion for heavy ion is discussed and the bubble formation rate is calculated. The following sections describe the present experiment to determine the threshold temperatures for bubble formation and the results and discussions.

2. Response of superheated emulsion to heavy ions

There is a minimum energy required for the nucleation to occur in superheated liquid, the so-called critical energy. The critical energy decreases with an increase in the operating temperature. By varying the operating temperature of the emulsions, ions of different energies can be detected. Different work has used different expressions for the critical energy. The critical energy, W, obtained from reversible thermodynamics can be expressed as

$$W = \frac{16\pi\gamma^3(T)}{3\{P_v(T) - P_l\}^2}, \tag{1}$$

where $\gamma(T)$ is the surface tension at temperature T, $P_v(T)$ is the vapour pressure of the liquid at temperature T, and P_l is the liquid pressure [10]. Another expression, E_c, for the critical energy including the evaporation heat required for nucleation was originally expressed by Bugg as

$$E_c = \frac{4\pi}{3}R_c^3 H + 4\pi R_c^2\left[\gamma(T) - T\frac{d\gamma}{dT}\right] + \frac{4\pi}{3}R_c^3 P_l, \tag{2}$$

where R_c is the critical bubble radius and H is the evaporation heat per unit volume of the liquid [11].

Nucleation can be induced by an ion from which energy transferred to the medium is larger than the critical energy. The transferred energy in the path length L of the ion is expressed by the product of L and track averaged LET over L, $\overline{(dE/dx)}_L$ $(= (1/L)\int_0^L (dE/dx)\,dx)$, which determines the minimum LET of the detectable ion by superheated emulsion. Defining the path length of the ion effective for the nucleation as effective length, L_{eff} and the minimum value of $\overline{(dE/dx)}_L$ for the nucleation as critical LET, $\overline{(dE/dx)}_{L_{eff},c}$, the critical energy is related to the critical LET of ions in the sensitive liquid by the following equations:

$$\frac{W}{kR_c} = \overline{\left(\frac{dE}{dx}\right)}_{L_{eff},c}, \tag{3}$$

$$\frac{E_c}{bR_{cl}} = \overline{\left(\frac{dE}{dx}\right)}_{L_{eff},c}, \tag{4}$$

where $L_{eff} = 2R_c$ in Eq. (3) and $L_{eff} = bR_{cl}$ in Eq. (4) and R_{cl} is the seed liquid radius which holds the same mass of superheated liquid as that of the critical size vapour bubble, and 'k' and 'b' are the nucleation parameters [12–15]. Details of the different nucleation models including the different nucleation parameters are described elsewhere [16].

The main component of the emulsions is glycerin. For the estimates of the energy loss of ions in the emulsions, the LET of the different ions in the glycerin used in the present experiments are shown in Fig. 1. The calculations were carried out for energies incident to the emulsions after passing through the materials between the ion beam exit port and the emulsions. The superheated emulsions used in the experiments were about 8 cm long and 1.5 cm in diameter. Most of the heavy ions