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EXPERIMENTS WITH A SUPERHEATED LIQUID

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THE usually observed boiling of a liquid is associated with the presence in the system of artificial nuclei for vapor formation. If these nuclei are removed and care is taken to ensure good wetting of the walls of the container by the liquid the latter can be appreciably superheated. In textbooks the question of the attainable degrees of superheating is not discussed, and the very fact of the possibility of a prolonged existence of highly superheated liquids is poorly known. It would be useful to introduce into practical instruction in physics appropriate laboratory experiments.

A liquid in the form of small droplets can be easily superheated to tens of degrees above its normal boiling temperature if one uses a suitable liquid surrounding medium. For saturated hydrocarbons of the methane series sulphuric acid can serve as such a medium. Figure 1 shows a schematic diagram of the apparatus which is used in the Physico-Technical Faculty of the Ural Polytechnical Institute both for research purposes and for student laboratory exercises. The glass tube 4 is filled with sulphuric acid. In flask 2 by means of a magnetic rotating stirrer 1 emulsification in sulphuric acid is made to occur for pentane, hexane or some other liquid under investigation. Droplets of diameter 0.1—0.5 mm reach the tube 4 through the connecting capillary 3 and float upwards in it. A heater is wound on the aluminum block 7. In the sulphuric acid a vertical temperature gradient is set up which gradually decreases with height and in the neighborhood of the window amounts to ~ 0.1 deg/mm. The droplets floating upward are superheated, and having reached a definite temperature become unstable with respect to the formation within them of incipient vapor bubbles and then evaporate explosively. The characteristic crackling produced by this can be clearly heard throughout the room. By introducing a thermocouple at the position of the explosion one can with good accuracy determine the corresponding temperature of the medium, and from that the temperature of the droplets. The correction associated with the failure of the rising droplet to attain the temperature of the surrounding medium can be reduced to a tenth of a degree or less[1].

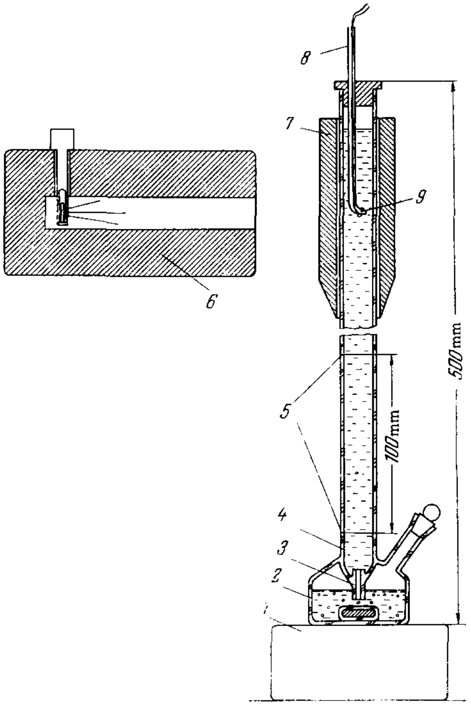

FIG. 1. Schematic diagram of apparatus for the determination of lifetime of droplets of superheated liquid.

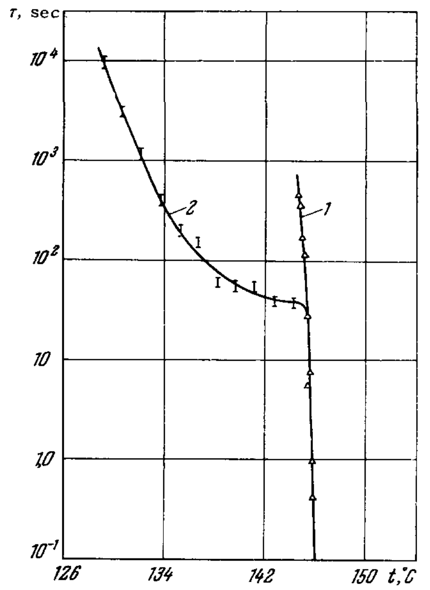

FIG. 2. Dependence of the mean life of droplets of superheated n-pentane on the temperature at atmospheric pressure: 1 – under natural conditions; 2 – under the action of γ-radiation; normal boiling temperature of n-pentane is 36.1°C.

More detailed information on the attainable superheating of a liquid can be obtained by bringing the droplets to rest at a given temperature. In order to do this one uses the glass tube 8 with a sealed off lower end. The end is slightly flattened, plane polished and has a small depression (~ 0.2 mm). Within the tube and in contact with its lower end there is inserted a measuring copper-constantan thermocouple with wire of diameter 0.1 mm. The horizontal "snout" 9 is displaced with respect to the axis of the tube. This enables one by rotating the tube in the teflon stopper either to place the "snout" in the path of the droplet, or to remove it to one side. Observations have shown that the droplets explode at the same temperature whether held against the snout or rising freely. Possibly the droplet is not in contact with the glass but is separated from it by a thin film of acid. A small bubble of vapor remains on the "snout" after the explosion; it can be easily shaken off by rotating the tube sharply, and this turns out to be sufficient to prepare the "snout" for the next experiment. It is more convenient to let the droplets come in short bursts, and to switch the stirrer on for 2–3 sec. The size of the droplet is determined from the time of rise between two marks 5 on the lower unheated portion of the tube. The distance between the marks is 100 mm.

The proposed method is simple and gives reproducible results in agreement with the theory of spontaneous boiling of a pure liquid[2-5]. Observation of the lifetime of superheated droplets shows a sharp temperature limit on the attainable degree of superheating. Curve 1 in Fig. 2 shows on a semilogarithmic scale the temperature dependence of the mean life τ of droplets of n-pentane with superheating exceeding 100°. The normal boiling temperature of n-pentane is 36.1°C. The data for the different droplets have been reduced to the same mass of 7×10^{-6} g which corresponds to a diameter of 0.28 mm at 20°C. For this mass of liquid according to the Dering-Volmer formula[2] (cf., also [6]) the value of $\tau = 1$ sec is reached at a temperature of 147°C.

The apparatus can also be used to determine the lifetime of droplets under the action of γ-radiation in the sensitive zone of the superheated liquid. Experiments of this kind are analogous to an investigation of the density of tracks of ionizing particles in bubble chambers. In both cases the determining factor is the probability of a triggered boiling of micro-volumes of superheated liquid. A source of Co^{60} is contained in the lead gun 6 placed on a rotating platform. The distance from the source to the apparatus is so chosen that the mean lifetime of droplets within a small temperature range would be of the order of tens of seconds. It is then convenient to record both short and long lifetimes. The use of a source of low activity (0.3 mg-equiv Ra) makes it safe to carry out the experiments.

At a given temperature the lifetimes are distributed in accordance with the Poisson law with a dispersion equal to the mean lifetime τ. From this follows the necessity of observing a large number of drops. Figure 2 shows the temperature dependence of τ for droplets of superheated n-pentane under the action of γ-radiation (curve 2). The data refer to a mass of 7×10^{-6} g and are obtained from experiments with 60–160 drops at each temperature. From the graph we can see the arbitrariness of the concept of a lower boundary to the region of sensitivity to radiation of superheated liquid. As the temperature is lowered from 144 to 134°C the mean lifetime of a droplet increases from 36 to 400 sec. With respect to bubble chambers this means a decrease in the density of the track by an order of magnitude with other conditions being the same.

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