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# 論 文 要 旨

THESIS SUMMARY

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| 専攻：<br>Department of | 物性物理学 | 専攻 | 申請学位（専攻分野）：<br>Academic Degree Requested | 博士<br>Doctor of | （　　理学　　） |
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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）


Crystallization of liquid in bulk state is a well-understood phenomenon. But crystallization in a restricted geometry is not well studied. Frost heaving seen in cold climates is a complex phenomenon with freezing of water in soil, which could produce large enough force to deform the stratum. Also in engineering, it relates to a number of applications such as freezing method, food freezing excavation. However, since it is not easy to eliminate the influence of non-uniformity of the medium and the impurities in such a complicated system, it is difficult to perform reproducible experiments. The crystallization in an ordinary medium is so complicated as to treat many processes such as transport of viscous flow and latent heat. Although it is well known that static properties such as elevation of melting pressure in a restricted space changes, basic physics for the dynamic properties is not understood very well. In order to approach such a problem, we investigate crystallization of $^4$He in aerogel as a porous material.

To use $^4$He is very beneficial on studying the crystallization in a porous material. $^4$He remains as liquid state down to absolute zero due to its large quantum effect. The liquid has a superfluid state below 2 K, and it's viscosity becomes very small. By performing experiments with superfluid $^4$He at very low temperature, it is possible to study in a clean environment without impurities. Owing to superfluid properties, we can ignore the effect of the viscosity of liquid even in a restricted geometry and owing to the peculiar property of crystallization at very low temperature, the latent heat is negligible in the study of crystallization. The quantum effects in the crystallization also can be expected. Superfluidity is a manifestation of quantum effects, $^4$He crystals are also a quantum solid whose atoms move by the zero point vibration. The supersolidity exhibiting superfluidity is a major interest in the study of $^4$He crystals. Quantum effects including supersolidity may appear as a new phenomenon in the dynamics of crystallization in restricted geometry.

Aerogel is a porous material having a fractal structure in the nano-scale region.Aerogel's porosity is from 90 to 99.5％ and its density is very low. Due to its high transparency, we are able to observe clearly crystallization in the porous material by direct visualization.

Previous research of crystallization in aerogel by visualization revealed the dynamical phase transition of the growth mode. It grows via avalanche in low temperature region and via creep of the interface in high temperature region. Measurement of crystallization rate indicated crystallization proceeds by macroscopic quantum tunneling at low temperatures, and, by thermal activation type at high temperatures.

In this thesis work, we investigated temperature dependence of nucleation processes and the $^4$He crystallization in aerogel by cooling.

Nucleation process was directly investigated by measuring the nucleation probabilities. Critical overpressures at which the first $^4$He crystal appeared during pressurization were measured 50 times at each temperature. The temperature dependence of the mean critical overpressure confirmed quantum nucleation in low temperature region and thermal nucleation in high temperature region. Crossover temperature was consistent with the result of crystallization rate measurement, which approximately coincided with the dynamic transition temperature of the crystal growth mode.

Meanwhile, Liquid pocket, which means a liquid region is surrounded by $^4$He crystals, happened to be formed in 96% aerogel. This pocket was found to crystallize at a certain temperature by cooling, and eventually completely crystallized. This observation showed the possibility that mass required for crystallization was transported through the solid.

Also by changing systematically the pressure and temperature, we attempted to elucidate the mechanism of crystallization by cooling. Crystallization started at a certain temperature by cooling not only with liquid pocket in aerogel but also with crystal partially filled or no crystal in aerogel. It was found that the crystallization started sharply at a given temperature from temperature sweep experiment. The temperature at which crystallization started by cooling depended on pressure. Since mass needs to be supplied to aerogel for crystallization, we proposed the possibility that mass transport occurred at a given temperature from bulk solid. Experiment of stepwise cooling provided temperature dependence of the crystallization rate, which increased toward low temperature.

Furthermore, from these crystallization experiments, we could obtain a crystallization phase diagram in aerogel. It suggested that melting pressure curve in aerogel has a peak unlike the bulk melting pressure at around the dynamical phase transition temperature. We are supporting the possible mechanism of mass transport for crystallization due to superfluid transition of dislocation core.