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EVAPORATION AND CONDENSATION IN $^3$He-$^4$He MIXTURE SYSTEMS

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Abstract. — Evaporation and condensation of mixed $^3$He-$^4$He system were studied experimentally using heat pulse technique. Analysis based on a weak coupling model of the surface state with the bulk excitations as an evaporation and condensation mechanism gave information on $^3$He surface trapped state which agrees with the surface tension measurements.

Calculation based on this model for the ratio of the cross section of surface $^3$He atoms for bulk excitations to that of surface $^4$He atoms gives 0.31.

Since Johnston and King's first experiment and Anderson's proposal of a model for evaporation several experimental and theoretical studies have been made on the evaporation and condensation from He II. However, a microscopic mechanism of the evaporation and condensation is still open to be understood in many respects at the present stage. We present first experimental data on the evaporation and condensation at the liquid-gas interface of $^3$He-$^4$He mixtures at 1.58 K.

Evaporating atoms from liquid film covering on the heater were detected by a microphone to measure the pressure variation of gas phase and also by a superconductor bolometer to measure the temperature variation by the pressure variation of gas phase and also by emitting bulk excitation. Assuming that the atoms evaporating from the liquid have a Maxwellian velocity distribution of liquid temperature, and the drift velocity \( v \) of the distribution of gas is equal to zero near the surface, this model leads to the following expressions for the number of evaporating and condensing atoms per unit area and unit time.

\[
N_i \text{ evp} = N_s \sigma_i \Gamma_1 \rho(T_i) \quad (1)
\]

and

\[
N_i \text{ con} = \frac{N_s \sigma_i \rho(T_i)}{(2\pi m_i kT_i)^{1/2}} \times (2\pi m_i kT_i)^{1/2}, \quad i = 3, 4 \quad (2)
\]

![Fig. 1](image-url)
where \( n_2(T_1) \) is the number of bulk excitations arriving at the surface of unit area per unit time effective for evaporating a \(^3\text{He}\) or \(^{4}\text{He}\) atom from the surface at liquid temperature \( T_1 \), and we assume \( n_2(T_1) = f(T_1) \exp(-\Delta_1/kT_1) \) where \( f(T_1) \) is slowly varying function. \( N_{s1} \) is the number of surface \(^3\text{He}\) or \(^{4}\text{He}\) atoms per unit area. For the low concentration of \(^3\text{He}\) we write \( N_{s1} = \alpha X N_s \), where \( \alpha \) is the enhancement factor of \(^3\text{He}\) concentration at the surface and \( N_s \) is the total number of atoms at the surface. \( \sigma_1 \) and \( \sigma'_1 \) are the average cross sections for the evaporation and condensation, and we assume from detailed balance \( \sigma_1 = \sigma'_1 \). \( \sigma_1 \) and \( \sigma'_1 \) are the partial pressures and the temperature of gas phase just above the surface. \( m_3 \) is the mass of \(^3\text{He}\) or \(^{4}\text{He}\) atoms.

For non-equilibrium conditions when a heat pulse \( W(t) \) is put into the liquid film from the heater or when the pressure variation \( \delta P(t) \) arrives at the surface of liquid film, we write following expressions for the conservation of energy in the liquid film and for the continuity of mass, energy and momentum flux in the gas phase between far field and interfacial boundary /1/.

\[
C_1 \frac{dT_1}{dt} + \sum_1 \left[ (\Delta_1 + 2kT_1) N_{i1} \text{ evap} - (\Delta_1 + 2kT_1 N_{i1} \text{ con} \right] = W(t) ,
\]

\[
\sum_1 (N_{i1} \text{ evap} - N_{i1} \text{ con} ) = \sum_1 (m_1 \Delta_1) \text{ vol} ,
\]

\[
\sum_1 (2kT_1 N_{i1} \text{ evap} - 2kT_1 N_{i1} \text{ con} ) = \sum_1 (m_1 \Delta_1) \text{ vol} ,
\]

and

\[
\frac{1}{2} \sum_1 \left[ (2m_1 kT_1)^{1/2} N_{i1} \text{ evap} - (2m_1 kT_1)^{1/2} N_{i1} \text{ con} \right] + P_s = P_0 + \delta P_{in} + \delta P_{out} ,
\]

where \( C_1 \) is the specific heat of the liquid film, \( \nu_1 \) is the number of \(^3\text{He}\) or \(^{4}\text{He}\) atoms in gas phase of unit volume. \( T_s \) and \( P_0 \) are the temperature and pressure in equilibrium, \( \delta P_{out} \) is the pressure variation of gas phase produced by the net evaporating atoms. We first solve \( \delta T_1 \), \( \delta P_{in} \) and \( \delta P_{out} \) from eq.(1,2,4-6) in terms of \( \delta T_1 \) and \( \delta P_{in} \) (\( \delta \) denotes deviation from thermal equilibrium) by setting \( \nu_0 = 0 \) and \( \nu_{in} \) expressing \( \nu_{out} \) and \( \nu_{in} \) terms of \( \delta P_{out} \) and \( \delta P_{in} \) from the relation of sound wave. From equation (3) we can get the maximum peak height \( \delta T_{max} \) of the temperature variation \( \delta T_1 \) and the maximum peak height \( \delta P_m \) of the pressure variation \( \delta P_{out} \) and we obtain the expressions normalized by their values at \( X_1 = 0 \) of \( \delta P_m / \delta P_{in} \), and \( (\delta T_{max} / \delta P_m) / (\delta T_{max} / \delta P_{in}) \). By equating these two expressions with our experimental data and by using a relation \( X/X_1 = a(n_2/n_0) \) \( (m_3/m_2)^2 \) which is obtained for small \( X_1 \) from the conditions of \( N_{i1} \) evap \( = N_{i1} \) con at equilibrium state, we obtain:

\[
\Delta_1 = 4.5 \pm 0.7 \times 10^{-3}, \alpha = 5.5 \pm 2.1, \sigma_0 / \sigma_4 = 0.31 \pm 0.02;
\]

where we assume \( \Delta_1 \) is equal to the latent heat of pure liquid \(^{4}\text{He}\) at 0 K.

The analysis of the data based on this model gives a fairly good agreement for the surface state with the measurement of surface tension for the \(^3\text{He}\)-\(^{4}\text{He}\) mixture. The condensation coefficient for \(^{4}\text{He}\) and \(^3\text{He}\) atoms has been known by reflection measurement /2,3/ to be close to unity. Our results together with this model seems to indicate that the cross section of surface \(^3\text{He}\) atoms to capture the bulk excitation is smaller than that of \(^{4}\text{He}\) atoms by the factor 0.3. It is not understood at present moment whether this discrepancy should be attributed to the difference of the experimental conditions (temperature range, concentration range, etc...) or if the model used here requires further improvements.

References

