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► To cite this version:

G. Lee, Philippe Lucas, A. Tyler, E. Vavasour. THE BÉNARD INSTABILITY IN A $^3\text{He}/^4\text{He}$ MIXTURE. Journal de Physique Colloques, 1978, 39 (C6), pp.C6-178-C6-179. 10.1051/jphyscol:1978679 . jpa-00218359

HAL Id: jpa-00218359

<https://hal.science/jpa-00218359>

Submitted on 1 Jan 1978

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THE BÉNARD INSTABILITY IN A $^3\text{He}/^4\text{He}$ MIXTURE

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Résumé.- Des expériences sont décrites démontrant que le mélange $^3\text{He}/^4\text{He}$ est un système très versatile pour l'étude de l'instabilité de Bénard à deux composants qui elle-même fournit une sonde pour la mesure du coefficient de thermo-diffusion du mélange.

Abstract.- Experiments are described showing that a liquid $^3\text{He}/^4\text{He}$ mixture is a very versatile system for investigating the two-component Bénard instability, which itself provides a probe for measuring the thermal diffusion ratio of the mixture.

The Bénard instability in a binary mixture has been the subject of considerable interest recently /1/ because thermal diffusion is an additional mechanism for producing gravitationally unstable density fluctuations besides that of thermal expansion. A liquid $^3\text{He}/^4\text{He}$ mixture is a much more versatile system for investigating this problem than the fluids hitherto used because of the large variation in the thermal diffusion ratio k_T and mass diffusion coefficient D near the λ and tricritical points /2,3,4/.

In a convection cell with horizontal rigid boundaries at which the temperature is fixed and in which there is a vertical heat current it is possible to show /5/ that the Rayleigh number R above which instability sets in and defined by

$$R = \beta \beta_c k_T g d^4 (1 + 1/M) / (\nu D T) \quad (1)$$

can take values between 1708 ($D/D_T \rightarrow \infty$, $M \rightarrow 0$) and 720 ($D/D_T \rightarrow 0$, $M \rightarrow \infty$) depending on the size of the quantity

$$M = D_T \{ D(1+A) \left[\frac{\beta}{\beta_c} - T \beta_T / (k_T \beta_c) \right] \}^{-1} \quad (2)$$

Here β is the temperature gradient, g is the acceleration due to gravity, ν is the kinematic viscosity, d is the cell spacing distance,

$\rho \beta_c = - (\partial \rho / \partial c)_{T,P}$, ρ , c , P and T are the mixture density, mass concentration pressure and temperature respectively, β_T is the expansion coefficient and $A = k_T^2 (\partial \Delta / \partial c)_{T,P} / (T C_{c,P})$ where $\Delta = \mu_3 - \mu_4$ is the difference in the chemical potentials of the mixture and $C_{c,P}$ is the specific heat. For convective instability to occur R must be positive, which implies that in a dilute mixture near its λ -point the heat current must be directed downwards so that β is positive, since k_T and β_c are both positive

but β_T is negative. The same applies below T_λ where the analysis pertains essentially to the one-component Bénard problem with an effective thermal conductivity /3/.

We have confined our experiments so far to cylindrical experimental cells containing a 15 molar per cent mixture of ^3He in ^4He which have diameter 2.5 cm and spacing 0.2 cm between the two horizontal copper end-plates. Near the λ -point our approach has been to fix the temperature of the lower plate and direct a heat current W downward through the upper plate. The boundary conditions are consequently not quite the same as those just described but are not expected to change the range over which R may vary.

Figure 1 shows experimental data on the dependence of the temperature $\Delta T(W)$ on the heat current W into a cell that has a fixed heat leak of $27 \pm 1.5 \mu\text{W}$ from the upper plate into the colder helium bath.

Fig. 1 : Dependence of temperature ΔT on heat current W into cell with lower plate maintained at $T_\lambda + 1 \text{ mK}$ (○), $T_\lambda - 0.095 \text{ K}$ (●).

Consequently the heat current through the mixture flows either downward or upward according to whether W is greater than or less than $27 \mu\text{W}$ respectively. $\Delta T(W)$ is measured from the ratio of two carbon resistance thermometers mounted on the cell plates and is given by $\Delta T(W) = \delta T(W) + \delta T_0$ where $\delta T(W)$ is the temperature difference between the plates and δT_0 is the magnitude of the temperature difference when $W = 0$. The data show that the thermal conductivity is enhanced when $W > 27 \mu\text{W}$ regardless of whether the mixture is above or below T_λ implying convection occurs for downward heat currents W_c only, which are at the most $1.5 \mu\text{W}$. Other data without the heat leak show $W_c < 0.2 \mu\text{W}$.

The small size of W_c is to be expected, for by substituting typical values of thermodynamic and transport parameters near T_λ into (1) and using $R = 1708$, we find $\delta T \approx 10 \mu\text{K}$ to be the minimum temperature difference above which convection may occur which corresponds to $W_c \approx 10^{-2} \mu\text{W}$.

Above T_λ the measured thermal conductivity is strongly dependent on the heat current through the mixture as can be seen from the data in figure 2.

Fig. 2 : Dependence of measured thermal conductivity K on $T - T_\lambda$ for cell which fixed heat current $2 \mu\text{W}(\bullet)$, $10 \mu\text{W}(\circ)$ is flowing. Solid line : non-convective data of Ahlers/7/.

These data were obtained with the heat leak disconnected so that W is the mixture heat current. We anticipate that these data should enable us to obtain the temperature dependence of k_T .

Finally we have performed some experiments above T_β , the temperature above which β_T is positive, without the heat leak and with the heat current directed vertically upward. In this regime thermal

oscillations were observed with periods of 20-30 minutes and the onset of convection was easily observable with $W \approx 10 \mu\text{W}$ which is to be expected in view of the much smaller size of $k_T \sim 10^{-3}$. This regime corresponding to $-1 < M < 0$, is one in which thermal oscillations have been observed in ordinary fluids by several observers /1,6/.

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