Torsional oscillator measurements of $^3$He-$^4$He mixtures confined in aerogel show evidence of a well defined phase separation region. This region is detached from the superfluid transition line, opening up a region of miscible superfluid mixture at high $^3$He concentration.

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Recent experiments studying the nature of superfluid transitions of $^4$He$^{1-3}$ and liquid-vapor phase separation of $^4$He$^4$ and N$_2^5$ entrained in porous silica aerogel found intriguing results that are distinct from that found with other porous media. Silica aerogel is a highly porous glass consisting of a tenuous network of SiO$_2$ strands interconnected at random sites.$^6$ The silica network is formed via a sol-gel process. In order to preserve the delicate structure, the solvent remaining from the gelation procedure is removed at a temperature that is above its critical temperature. The open volume fraction of the aerogel ranges from 0.85 to 0.998; in other words, solid silica constitutes from 15 to 0.2 percent of the total available volume.$^7$ Vapor pressure isotherm measurements indicate an extremely large surface area, typically 580 to 800 m$^2$/gm.$^9$ If we combine the surface area and density information, the silica network in aerogel can be modeled as thin strands of roughly 30Å in diameters. The random and near fractal-like network,$^9$ the narrow strand diameter and the extreme high porosity are some of the properties that separate light aerogel from other porous systems.

In spite of the random environment provided by aerogel, an exceedingly sharp superfluids transition is found for the entrained $^4$He. Whereas the transition temperature $T_c$ is depressed from the bulk lambda temperature $T_\lambda$ by only several millikelvins, the nature of the transition for $^4$He in aerogel of 0.94 and 0.91 open volume fraction is completely altered.$^{1-3}$ If the temperature dependence of the superfluid fraction $\rho_s/\rho$ near $T_c$ is expressed as a simple power law of the form

$$\rho_s/\rho = [(T_c - T)/T_c]^\zeta$$  \hspace{1cm} (1)$$

then the critical exponent $\zeta$ is found to assume a value of 0.81, significantly larger than 0.672, the exponent found for bulk $^4$He. The transition is extremely sharp in that the power law as shown in equation (1) is found to provide a very good
description of the $\rho_s/\rho$ data well into a reduced temperature $t = (T_c - T)/T_c$ of $10^{-4}$. There is yet no complete, quantitative understanding of the superfluid density and the heat capacity results of $^4$He in aerogel. It is generally agreed that the non-bulklike critical exponent is a consequence of the correlated quenched impurities in the form of the silica structure.\(^{10}\)

Measurements were also made of $^4$He and $N_2$ confined in aerogel near their respective liquid-vapor critical temperatures. Heat capacity and vapor pressure isotherm measurements found evidence of liquid-vapor-like phase separation of $^4$He in aerogel that terminates at a critical point that is 31 mK below the bulk value at 5.198K.\(^4\) A liquid-vapor phase coexistence region and a critical point of $N_2$ in aerogel were found via a slight scattering experiment.\(^5\) Due to the strong attraction of $N_2$ and $^4$He to the silica strands, the "vapor" phase is likely to consist of the vapor and a thin adsorbed liquid film coating the silica strands. The light scattering experiment shows that the linear dimension of the vapor and liquid domains remain on the order of the wavelength of light (instead of macroscopic dimension) throughout the entire two-phase coexistence region. The liquid-vapor coexistence region in the $\rho - T$ plane of $^4$He and $N_2$ in aerogel of 0.94 open volume fraction near their respective $T_c$ are shown in Fig. 1.

This figure shows that the coexistence regions for both $^4$He and $N_2$ in aerogel at temperatures not far below $T_c$ are substantially narrower than that of the bulk system. For $^4$He in aerogel the width at a specific reduced temperature is fully fourteen times smaller than that of bulk. For $N_2$ the difference is 2.6 times. Recently, vapor pressure isotherm measurements found evidence that the narrow coexistence region shown in Fig. 1 for $^4$He in aerogel widens below 4.9K and becomes comparable in width to that of the bulk liquid-vapor coexistence region.\(^{11}\)

In this paper we report the result of a systematic torsional oscillator study of $^3$He-$^4$He mixture entrained in aerogel of 0.98 open volume fraction. Although the silica strands of the aerogel occupy only 2% of the total available volume, the effect on the $^3$He-$^4$He phase diagram is profound. In bulk mixtures, the superfluid transition temperature decreases with increasing $^3$He concentration and terminates at the tricritical point at $T = 0.872K$ and $X_3=0.669$. Here $X_3 = N_3(N_3 + N_4)^{-1}$ is the (molar) $^3$He concentration with $N_3$ and $N_4$ being respectively the number of $^3$He and $^4$He atoms in a mixture. Below the tricritical point the mixture phase separates into $^3$He and $^4$He rich regions (see Fig. 2)

In spite of the random environment, mixture confined in aerogel appear to undergo phase separation with well-defined coexistence boundaries, as in the case of liquid-vapor phase separation. The coexistence region, however, is detached from the superfluid transition line, thus removing the tricritical point and opening up a region of miscible superfluid that is rich in $^3$He. The aerogel sample used in this experiment was jelled and grown directly inside the cylindrical torsional cell of 0.70 cm in diameter and 0.96cm in height.\(^7\) The major advantage of growing aerogel in situ is the elimination of macroscopic void and hence bulk fluid in the cell. If aerogel samples were cut from stock and glued into a cell, it is more difficult to avoid the presence of void spaces.\(^2\) The torsional oscillator was operated at a resonant frequency near 391 Hz. Measurements were made in a $^3$He and in a dilution refrigerator cryostat. Each experimental run started with a pure $^3$He sample; subsequent samples were prepared by successive dilutions of $^4$He to the