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Technical Report

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I. Introduction

Low energy neutrons provide a unique opportunity for the visualization of interesting dynamical systems. Particularly for liquid helium mixtures, there are a number of very basic issues of current interest which can only be addressed by means of very novel techniques. The technique which we developed under this proposal is one of these and is designed to address specific issues for $^3$He-superfluid-$^4$He mixtures. These are: convection in these mixtures, and heat flow when the $^3$He concentration is very low.

The neutron imaging device which we developed is potentially very useful for investigating the convection patterns when these mixtures are subjected to an adverse density gradient. There are a number of intriguing results obtained without the benefit of imaging. A full understanding of these results will depend crucially on obtaining images of the convection pattern. The second issue of interest, heat flow in very dilute superfluid mixtures, poses a particularly puzzling question. The expected divergence of the effective conductivity with vanishing $^3$He concentration, $X$, is not seen experimentally. This effect is intimately tied to the distribution of $^3$He in the direction of heat flow. However, no information on the distribution is available. The device which we constructed is potentially capable of addressing this need.

The technique can also be used with any system in which there is a spatially varying distribution of neutron absorbers. Hence, it is have broad
II. Results from this project

We have developed the necessary apparatus to carry out the proposed experiments with support from the DOE (grant DE-FG05-88ER45371) at the level of $120,000 over the past three years. This support involved $60,000 which went directly to Brookhaven National Laboratory to develop the heart of the measurement, a High Resolution Two-Dimensional Detector (HRTDD) for neutrons, with the balance for the support of a graduate student. Support at the level of $20,000 was provided for a graduate student and miscellaneous expenses.

We have produced the following results using this very modest support:

a. A neutron HRTDD for imaging spatial structures in which the distribution of neutron absorbers is nonuniform. This is sketched in Figure 1a and d; it consists of a highly collimated beam of thermal neutrons from a wide-area source (not shown), the experimental region containing neutron absorbers, and an array of neutron detectors. The detectors are read by an automated data-taking system and stored. We briefly consider the various components in the paragraphs below.

The highly collimated neutron beam is obtained by using 1m lengths of small diameter (1.0mm) stainless steel tubing plated with cadmium, a highly
Figure 1: Several schematics and data. a. a layer of a convecting superfluid mixture sketching convection rolls. b. initial results using a single neutron pencil-beam. c. an experiment on one-dimensional profiles. d. a neutron HRTDD experiment to simultaneously measure the concentration distribution at all points in a convecting layer.
efficient neutron absorber. These plated tubes are close-packed to form an array $1''\times2''$ which fits into the exit shield of the neutron reactor. The source of the neutron beam is Brookhaven National Laboratory’s HFBR (High Flux Beam Reactor).

The highly collimated neutron beam traverses the experiment and undergoes attenuation. The experiment must be cooled below the superfluid onset temperature, $T_s = 2.172K$. This entails the use of dewars and other cryogenic equipment which are now in the final states of preparation. Minimal attenuation due to the dewars is achieved because the beam traverses only aluminum vacuum jackets before and after the experimental region. Therefore, nearly all the observed attenuation of the beam occurs due to the $^3He$ in the fluid layer under study. In any event, this background attenuation and any nonuniformity in the beam/detector combination can be determined by making measurements with the dewars and empty cell in place but with no liquid helium sample in the conductivity/convection cell. Initial demonstration data, clearly showing convection rolls, obtained with a very simple version of this experiment are presented in Figure 1b.

The HRTDD has been constructed using state-of-the art $^3He$ gas techniques. The detector has been designed to achieve a spatial resolution of 500$\mu m$ over a $5\times5cm^2$ area. This is accomplished by using two sets of finely spaced wire electrodes oriented at right angles to one another. These wires are housed in a $^3He$-gas-filled chamber with a 1.25$cm$ thick single crystal
sapphire window. The design criteria for the spatial resolution is realized by using a sophisticated position sensing algorithm. A complete description of the operation of such a detector can be found in the article by Boie et al.\textsuperscript{4} A data collection/display system has been constructed separately which allows for a continuous display of the detectors output. Figure 2 shows the results of a preliminary test of the HRTDD. Shown in the figure is a photograph of the computer screen used to display the detector output. The pattern of bright spots has been formed by passing neutrons through a pattern of 1.0mm holes drilled in a cadmium mask. Preliminary analysis of the data suggests that our 0.5mm spatial resolution has been achieved.

Although the initial experiments are designed to employ simple transmission techniques, future experiments should incorporate tomographic reconstruction techniques similar to those used in x-ray CAT scanners and PET machines. This would allow for a three-dimensional reconstructions of the systems under study.

b. A cryostat capable of maintaining a highly controlled thermal environment over a temperature range of $0.4K \leq T \leq 6K$. Over this temperature range, we have temperature resolution of $\approx 0.3\mu K$.

c. Three papers were produced. The line of research pursued in these papers differs from the original direction of the imaging of flows in superfluid helium. This shift of directions was neccessitated by the extended shut-
Figure 2: Computer image of the neutron transmission through a cadmium plate with a pattern of 1mm diameter holes, taken recently at the HFBR. Down of the HFBR neutron source at Brookhaven National Laboratory, the planned site of the original experiments. Instead of probing flows in superfluid mixtures, we have conducted experiments on convection in binary room-temperature mixtures, specifically, ethanol in water, as well as experiments on convection in pure fluids such as pure water and pure ethanol. One of the striking features of convection in binary mixtures is the occurrence of traveling waves. Our measurements on binary mixtures led naturally to
those described in the last paper,\textsuperscript{2} where we present results for a novel traveling wave state which we have discovered in a pure convecting fluid, namely water. This state is of considerable interest in the nonlinear dynamics community because it arises in an $O(2)$ symmetry for which recent theories have been developed.\textsuperscript{3} The abstracts of the relevant papers are attached.
References


