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**COVER SHEET
FOR TRIP REPORTS SUBMITTED TO THE
OFFICE OF ENERGY RESEARCH**

Destination(s) and Dates for
Which Trip Report Being Submitted: Grenoble, France (12/09-20/90)

Name of Traveler: H. A. Mook

Joint Trip Report ☐ Yes
☒ No

If so, Name of Other Traveler(s): _____

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ORNL

FOREIGN TRIP REPORT

ORNL/FTR-3859

DATE: January 4, 1991

SUBJECT: Report of Foreign Travel of H. A. Mook, Jr., Corporate Fellow, Neutron Scattering Section, Solid State Division, ORNL

TO: Alvin W. Trivelpiece

FROM: H. A. Mook, Jr.

PURPOSE: To perform neutron scattering studies of high-temperature superconducting materials at the Institut Laue-Langevin (ILL).

SITES VISITED: 12/09-20/90 Institut Laue-Langevin, S. Hayden
Grenoble, France

ABSTRACT: The traveler was given beam time at the ILL to continue neutron scattering work on high-temperature superconductivity. The unique facilities at the ILL for both high-energy and low-energy neutron instrumentation made the experiments possible. The measurements consisted of two basic types. The first of these is the study of the nature of spin fluctuations in high- T_c materials. This work is fundamental to the mechanism that is responsible for the high-transition temperatures. The second consisted of experiments on the flux lattice in high-temperature superconductors. The flux lattice has interesting physics in its own right and is important in understanding the current-carrying capability of superconductors.

MASTER

INSTITUT LAUE-LANGEVIN (ILL),
GRENOBLE, FRANCE

The high-flux isotope reactor (HFIR) at Oak Ridge National Laboratory (ORNL), which has the highest flux of any reactor in the U. S., is now available for neutron scattering research. Although the HFIR is an excellent reactor for many types of neutron experiments, it does not have a hot source for epithermal neutron research or a cold source for low-energy neutron experiments. There is a cold source associated with the HFBR reactor at Brookhaven National Laboratory, but it is not incorporated as an integral part of the neutron reflector and thus has a low flux. This means that travel to the ILL is necessary to perform certain kinds of experiments. I expect to visit the ILL approximately twice a year on an indefinite basis. It is indeed fortunate that we can do this as the neutrons are free if one's proposal is accepted, despite the fact that the U. S. makes no contribution to the operation of the facility. These trips to the ILL have proved to contribute greatly to the ORNL program on high- T_c superconductivity. This year I have been invited to give talks at the West Coast Gordon Conference on Superconductivity, the Conference on Magnetism and Magnetic Materials, the March Meeting of the American Physical Society, and the Conference on Rare-Earth Materials, to discuss the neutron scattering work which I performed at the ILL.

Because of some shifting of the experimental schedule, I departed for Grenoble on December 8, instead of December 5, as originally planned. This proved to be a poor decision as I got trapped in the worst snow storm that Europe has had for several years. Nevertheless, upon my arrival, everything that I had requested was available for the experiments, such as dilution refrigerators and specialized high-field cryomagnets; and I was able to start to work immediately. I had beam time for 4 experiments this time which was plenty to keep me fully occupied—usually enough for about 20 hours a day. Fortunately, I had a lot of excellent help. The main object of this trip was to continue work on the high-temperature superconductors. The experiments were of two main types: the first concerning studies of spin fluctuations in high- T_c materials and the second consisting of small-angle neutron studies of

the flux lattice in high- T_c materials. I shall discuss the measurements on the spin fluctuations first.

We have had a very successful ongoing collaboration with G. Aeppli of AT&T Bell Laboratories and S. Hayden of the ILL on the so-called 2-1-4 alloy system $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$. For $x = 0$, the material is a spin one-half two-dimensional Heisenberg antiferromagnet, and we have been successful in characterizing the magnetic excitations in this material over a wide energy range. The high-energy excitations were studied on the hot source triple-axis spectrometer IN1, while the lower energy excitations were determined with the standard neutron triple-axis spectrometer IN8 and the cold neutron triple-axis spectrometers IN12 and IN14. As x is increased to around 0.05, the material becomes metallic, and we have found that the material has a spin glass ground state with a short (15 Å) temperature-independent spin-spin correlation length. Our measurements show that the frequency-dependent susceptibility $\chi(\omega)$ can be described well by a single function $\tan^{-1}(\omega/\Gamma)$, where Γ is the spin wave damping. This fits the result expected if the spin dynamics are described by a marginal Fermi liquid. The present series of measurements concentrated on material where x is about 0.15, and the material is superconducting with a transition temperature of about 33 K. Measurements on the cold neutron spectrometer IN14 made at 50 mK show that the magnetic ground state of this material is an incommensurate spin structure with four contributions found around the magnetic Bragg point observed for La_2CuO_4 . We could find no frozen component to the spin fluctuations even at 50 mK, although one may exist at still lower temperatures. The spin excitations were characterized using the IN8 and IN1 spectrometers. They were found to peak in momentum space at the incommensurate positions and to have a steep dispersion. The excitations were found to be very different than those found for the metallic phase in both their lifetimes and in their energy dependence with momentum. More measurements are needed and will be made both at HFIR and on the specialized spectrometers at the ILL.

The small-angle scattering measurements of the Abrikosov flux lattice were made on the D17 and D11 spectrometers. They were made in collaboration with T. Forgan of the University of Birmingham and D. Paul of

the University of Warwick, England. We had valuable help from a postdoctoral student, S. Lee, and a thesis student, B. Cubitt, both from the University of Birmingham. This help was imperative as the experiments needed attention 24 hours a day. The above collaboration has been the only group to observe successfully the flux lattice in high- T_c materials with neutrons. The work is a continuation of our previous work done mostly at the ILL but to some extent at HFIR with the help of G. D. Wignall. The measurements are exceedingly important as neutron scattering is the only way to observe directly the fluxoid lattice in magnetic fields needed for typical superconducting applications.

D17 is a low-resolution spectrometer in which we used high-magnetic fields (to 4 T), while D11 is a high-resolution machine. The neutron flux for both spectrometers is about a factor of 10 higher than any available in this country. We first used D17 to extend to higher fields results that had been acquired for Bi(K)BaO_3 at the small-angle scattering spectrometer at HFIR. Measurements made at HFIR for 0.3 T showed that the flux-lattice scattering intensity fell off rapidly at temperatures in excess of 26 K. However, we found, using D17, that for higher fields the intensity disappeared at about one-half this temperature. It appears that there may be two types of superconducting behavior in this material depending on whether the applied field is lower or higher than approximately 0.5 T. We will try to sort this out by making further measurements at low fields at HFIR. The fluxoid lattice was observed to be triangular when the field is applied along the [111] direction.

Most of our measurements were made on $\text{YBa}_2\text{Cu}_3\text{O}_7$. We were able to observe the flux lattice at fields up to 4 T. We determined the structure of the flux lattice for the first time and were surprised to find that it appeared to be square when the applied field is directed along c . The scattering pattern is found to coincide with the twin boundaries in the crystal in this case. The temperature dependence of the scattering from the fluxoid lattice was measured for various applied fields. In the D11 experiments we investigated the structure of the fluxoid lattice for the case where the field is applied at an angle to the c axis. If the field is applied at an angle of 20° from the c axis, the fluxoid lattice is triangular but not well defined. For a 10° angle, a triangular

lattice is found with a different orientation. We also made temperature-dependent measurements for the triangular lattice. We are really starting to get a lot of information about the nature of the flux lattice, and this is being analyzed to see how it compares with various theories that are available. The measurements are also important in understanding current flow in these materials. Our observation of the connection between the twin boundaries and the fluxoid lattice structure is important in understanding how fluxoid pinning takes place in high- T_c superconductors.

Each visit to the ILL leaves one with a sense of amazement at the difference between the scale of the neutron program in Europe and our own program in the U. S. At every visit, a new spectrometer is running and new programs are under way. Small-angle and backscattering instruments are now approaching completion in the second guide hall. I had lunch one day with the director of the ILL, P. Day. A proposal for a new general upgrade is now in preparation and will certainly take place at a substantial funding level—the exact amount not yet determined. New buildings are going up, some to be shared with the new European light source which is under construction next door to the ILL. Progress is being made at the smaller neutron sources in Europe as well, and the reactor in Berlin is to start up shortly. One always enjoys the liveliness and the vitality of the ILL and the many discussions with the staff and visitors. We hope the Advanced Neutron Source will provide this kind of environment for the U. S. scientific community. It is the only hope we have for the future of neutron scattering in this country.

CONCLUSIONS

Our measurements went very well, and we obtained excellent results from both the fluxoid-lattice measurements and the experiments on the spin fluctuations. All our equipment performed perfectly, and we had no trouble with the reactor. We expect to make further measurements using the specialized equipment at the ILL to complement our experiments at HFIR. The ILL continues to expand and improve its equipment, and a large new

initiative for additional facilities is being developed at the present time. A trip to the ILL is always stimulating as one is able to meet with so many scientists and discuss their latest results.

APPENDIX

ITINERARY

Dates	Location	Individuals Contacted	Subject of Discussion
12/08/90	Travel from Oak Ridge, Tennessee, to Grenoble, France, via plane		
12/09-20/90	Institut Laue-Langevin, Grenoble, France	S. Hayden P. Day B. Dorner P. Timmins	To perform neutron scattering experiments; discussions on future plans and funding levels at the ILL; and updated informa- tion on present construction and future plans in the small-angle scattering program.
12/21/90	Travel from Grenoble, France, to Oak Ridge, Tennessee, via plane		

END

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