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FLUX LATTICE MELTING IN THE HIGH Tc SUPERCONDUCTORS

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ONE OF THE IMPORTANT ISSUES FOR TECHNOLOGICAL APPLICATION OF THE HIGH Tc SUPERCONDUCTORS IS THEIR BEHAVIOR IN A MAGNETIC FIELD. A VARIETY OF EXPERIMENTS INCLUDING ELECTRICAL TRANSPORT[1], MECHANICAL OSCILLATORS[2] AND MAGNETIC DECORATION[3] HAVE SUGGESTED THAT THESE MAGNETIC PROPERTIES WILL MAKE APPLICATIONS MORE DIFFICULT THAN ORIGINALLY ANTICIPATED.

IN A TYPE II SUPERCONDUCTOR, WHICH INCLUDES ALL KNOWN OXIDE SUPERCONDUCTORS, WHEN A MAGNETIC FIELD IS APPLIED IT BREAKS UP INTO DISCRETE BUNDLES EACH CONTAINING ONE QUANTUM UNIT OF FLUX. THESE FLUX LINES ORGANIZE THEMSELVES INTO A FLUX LATTICE WHICH IS HEXAGONAL IN SHAPE. THE FORMATION OF THIS HEXAGONAL LATTICE IS IMPORTANT FOR A VARIETY OF REASONS. THIS LATTICE WITH LONG RANGE POSITIONAL ORDER WILL HAVE A FINITE SHEAR MODULUS WHICH WILL ALLOW FOR HIGH CRITICAL CURRENTS IN THESE MATERIALS. THIS CAN BE SEEN BY THE FOLLOWING ARGUMENT. WITH A CURRENT FLOWING IN THE SAMPLE EVERY FLUX LINE WILL BE SUBJECT TO A LORENTZ FORCE WHOSE MAGNITUDE IS GIVEN BY THE CURRENT TIMES THE FIELD. IF THE FLUX LINES MOVE IN RESPONSE TO THIS FORCE THEN ENERGY WILL BE DISSIPATED AND THE SUPERCONDUCTING STATE WILL BE DESTROYED. THIS CAN BE AVOIDED BY HAVING THE FLUX LINES PINNED TO DEFECTS IN THE SAMPLE. HOWEVER IT IS NOT POSSIBLE TO PIN ALL OF THE LINES AS TO DO SO WOULD INTRODUCE SO MUCH DISORDER THAT THE TRANSITION TEMPERATURE WOULD BE LOWERED FOR ELECTRONIC REASONS. THE SOLUTION WHICH WORKS IN CONVENTIONAL MATERIALS IS TO PIN JUST A FEW OF THE FLUX LINES WITH DISORDER AND HAVE THE REST OF THEM HELD IN PLACE BY THE FINITE SHEAR MODULUS OF THE LATTICE. IT IS THE EQUIVALENT OF HOLDING A CARPET IN PLACE BY NAILING IT IN JUST A FEW PLACES. THEREFORE IT CAN BE SEEN THAT THE FORMATION OF A FLUX LATTICE MAY BE CRUCIAL TO OBTAINING HIGH CRITICAL CURRENTS IN THESE MATERIALS.

THE PROBLEM WHICH HAS COME TO LIGHT IS THAT IN THESE MATERIALS THE FLUX LATTICE MELTS WELL BELOW THE SUPERCONDUCTING TRANSITION TEMPERATURE. THIS CAN BE SEEN IN A VERY DRAMATIC FASHION BY USING VARIABLE TEMPERATURE FLUX LATTICE DECORATION EXPERIMENTS AS SHOWN IN THE FIGURE.

IN A DECORATION EXPERIMENT MAGNETIC PARTICLES ARE EVAPORATED ONTO THE CRYSTAL SURFACE AT LOW TEMPERATURES WHEN THE FLUX LATTICE IS PRESENT. THESE PARTICLES ARE MAGNETICALLY ATTRACTED TO AND DECORATE THE FLUX LINES. ONE CAN THEN WARM UP THE SAMPLE AND OBSERVE THE POSITIONS OF THE FLUX LINES BY LOOKING FOR THE PILES OF MAGNETIC PARTICLES WHICH HAVE BEEN LEFT BEHIND. THE VARIABLE TEMPERATURE FLUX LATTICE DECORATIONS SHOWN IN THE FIGURE SHOW THAT AT TEMPERATURES WELL BELOW THE SUPERCONDUCTING TEMPERATURE THE FLUX LATTICE IS A LIQUID.THUS THIS LOWER FLUX LATTICE MELTING POINT NOT THE THE MUCH HIGHER TRANSITION TEMPERATURE WILL BE THE UPPER LIMITING TEMPERATURE FOR MOST APPLICATIONS OF THE OXIDE SUPERCONDUCTORS. THIS MAKES POTENTIAL APPLICATIONS FOR THESE MATERIALS HARDER TO ACCOMPLISH. IT MAY BE POSSIBLE THAT WITH PROPER PROCESSING OF THESE MATERIALS PINNING CAN BE INTRODUCED WHICH WILL REPLACE THE NEED FOR A FLUX LATTICE. THIS IS A DIRECTION IN WHICH MUCH WORK IS BEING DONE BY WORKERS AROUND THE WORLD. OUR RESULTS DO NOT UNAMBIGUOUSLY IMPLY THAT THE OXIDE SUPERCONDUCTORS WILL BE IMPOSSIBLE TO USE IN APPLICATIONS BUT MERELY POINT OUT THE NECESSITY FOR FURTHER RESEARCH IN TRYING TO UNDERSTAND THE STATICS AND DYNAMICS OF THE FLUX LATTICES IN THESE MATERIALS[4].

REFERENCES

1. T.T.M.PALSTRA, B.BATLOGG, L.F.SCHNEEMEYER AND J.V.WASZCZAK, PHYS. REV. LETT. 61, 1662 (1988).

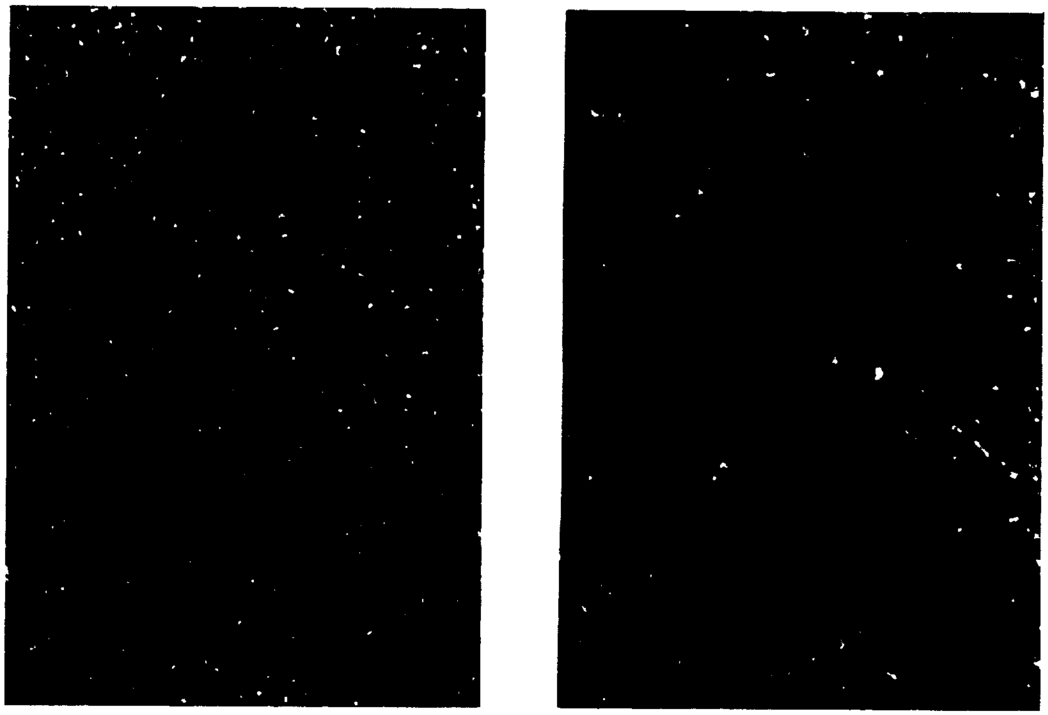
2. P.L.GAMMEL, L.F. SCHNEEMEYER, J.V. WASZCZAK AND D.J.BISHOP, PHYS. REV. LETT. 61, 1666 (1988).

3. P.L.GAMMEL, D.J.BISHOP, G.J.DOLAN, J.R.KWO, C.A.MURRAY, L.F.SCHNEEMEYER AND J.V.WASZCZAK, PHYS. REV. LETT. 59, 2592 (1987).

4. FOR A REVIEW OF MANY OF THE ISSUES RELEVANT TO FLUX LATTICES IN THE HIGH Tc SUPERCONDUCTORS ONE CAN SEE THE ARTICLE IN *PHYSICS TODAY*, MARCH 1989 , PAGE 17.

IMAGE SOLID AND LIQUID LATTICE

T=15K



YBCO (SOLID) BSCCO (LIQUID)

FOR $\tau = 1\text{sec}$ $D = \langle x \rangle^2 / \tau$

VORTEX DIFFUSIVITY:

$$D_L >> D_S$$

This electron microscope photograph shows simultaneous flux lattice "decorations" of yttrium barium copper oxide (left) and bismuth strontium calcium copper oxide (right) at 15K in a field of 20 gauss. In contradistinction to the yttrium barium copper oxide, the flux lines in the bismuth strontium calcium copper oxide move significantly during the decoration time of about one second. This measurement provides convincing visual evidence that the flux lattice in bismuth strontium calcium copper oxide melts into a liquid significantly below the critical temperature for a superconductor.