Lawrence Berkeley National Laboratory
Recent Work

Title
PROPAGATION OF MIXED STATE PHASE BOUNDARY IN TYPE-II SUPERCONDUCTOR

Permalink
https://escholarship.org/uc/item/3bd6m6f8

Author
Boyd, R.G.

Publication Date
1965-10-01

eScholarship.org
Powered by the California Digital Library
University of California

UCRL-16470

University of California

Ernest O. Lawrence Radiation Laboratory

PROPAGATION OF MIXED STATE PHASE BOUNDARY IN TYPE-II SUPERCONDUCTOR

TWO-WEEK LOAN COPY

This is a Library Circulating Copy which may be borrowed for two weeks. For a personal retention copy, call Tech. Info. Division, Ext. 5545

Berkeley, California

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Submitted to Phys. Rev. Letters

UCRL-16470

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

PROPAGATION OF MIXED STATE PHASE BOUNDARY IN TYPE-II SUPERCONDUCTOR

R. G. Boyd

October 1965

PROPAGATION OF MIXED STATE PHASE BOUNDARY
IN TYPE-II SUPERCONDUCTOR

R. G. Boyd

Inorganic Materials Research Division,
Lawrence Radiation Laboratory, University of California
Berkeley, California

October 1965

Recently R. B. Flippen[1] reported some measurements on the velocity of magnetic field penetration of thick-walled cylindrical type-II superconductors. In this letter we derive an expression for the velocity in thick slabs.

Consider a semi-infinite solid extending in the positive x-direction with its surface at $x = 0$. We turn on at $t = 0$ an external magnetic field H parallel to the surface, with constant sweep rate $\overset{o}{H}$. Flux initially penetrates at a field which we shall consider to be negligibly low, and thereafter the mixed state phase boundary propagates to the right with some velocity v. We shall assume that the external field H is less than H_{c2} during the time region of interest, to avoid the appearance of a normal phase chasing the mixed state phase.

As in the type-I superconductor case,[2] the motion of the phase boundary is controlled by eddy currents in the part of the metal which is penetrated by flux. We shall assume that the relation between current J and electric field E given by Kim et al.[3] is obeyed:

$$J = J_c + (H_{c2}E)/(\rho H). \qquad (1)$$

This relation fails to hold when J or H are too large, but the limits of applicability must at present be established experimentally for each specimen. In general, it holds over the widest range in H if $T/T_c \ll 1$,

$H_{c1} \approx 0$, and the H_{c2} of the specimen is not paramagnetically limited. The limitation on current is still an unknown quantity.

Introducing the vector potential A, we get from Maxwell's equations in our one-dimensional case

$$\frac{d^2A}{dx^2} = \frac{4\pi}{c}\left[- J_c + \frac{H_{c2}}{\rho c}\ \frac{dA/dt}{dA/dx}\right] . \qquad (2)$$

To make the problem tractable, we assume that the resistive critical current J_c is constant, as in the naive form of the Bean model.[4]

The equation is non-linear, but has a simple wave solution. If we assume $A = A(x-vt)$, then we find

$$H = - \frac{4\pi}{c}\left(J_c + \frac{H_{c2}v}{\rho c}\right)(x-vt). \qquad (3)$$

The magnetic field is linear in x and translates to the right with velocity v. The current is uniform throughout the mixed state region. When H_{c1} is not negligible however (as at the phase boundary itself), then physical intuition suggests the presence at the phase boundary of a "surface current" of order of magnitude $(cH_{c1})/(4\pi)$.

If $J_c = 0$, then

$$v^2 = \frac{\rho c^2}{4\pi H_{c2}}\ \dot{H} , \qquad (4)$$

whereas if J_c is large, then

$$v = \frac{c\dot{H}}{4\pi J_c} . \qquad (5)$$

Since the resistivity appears only in the ratio ρ/H_{c2}, the velocity v is independent of resistivity in the dirty limit, in contrast to propagation velocities in normal metal where $v \propto \rho$.

No detailed comparison between our results and Flippen's data is possible. We have been unable to solve the equivalent equations for a thick walled cylinder. Furthermore, in his specimen of Nb we cannot consider H_{c1} to be negligible, nor can we assume that only the mixed state phase is present, since it appears that the external field may have exceeded H_{c2} before the wave front reached the interior of his cylinder. Nevertheless, our expression for v gives the correct order of magnitude for Flippen's results on Nb 25% Zr, and we have accounted for the fact that phase velocities in his experiment on Nb depended only weakly on resistivity.

We suggest that subsequent experiments be performed on thin-walled cylinders of substances with negligible pinning and with $H_{c2} \gg H_{c1}$.

This work was supported under the auspices of the United States Atomic Energy Commission.

FOOTNOTES

1. R. B. Flippen, Phys. Letters 17, 193 (1965).
2. A. B. Pippard, Phil. Mag. 41, 243 (1950).
3. Y. B. Kim, C. F. Hempstead, and A. R. Strnad, Phys. Rev. 139, A1163 (1965).
4. C. P. Bean, Rev. Mod. Phys. 36, 31 (1964).

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.