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An Evaluation of Electromagnetic Response of Unconventional Superconductors and Evaluation of Dynamic Conductivity of Unconventional Super Conductors

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ABSTRACT

This paper presents a study the electromagnetic response of unconventional superconductor and evaluated the dynamic conductivity of unconventional superconductor. For such superconductor the dynamic conductivity σ depends upon the frequency, temperature, scattering rate, phase shifts, find orientation relative to energy gap. The field orientation is such that $\bar{E}$ points either into the dimension of vanishing energy gap ($\bar{E}_i\hat{1}$ for the polar state and $\bar{E}_i\hat{1}$ for the ABM state) or into the dimension of maximum energy gap. Only the limiting phase shift δ=0 (Born approximation) and $\delta = {}^{\pi}/_{2}$ (unitary limit) have been investigated. The real and imaginary part of σ arc normalised write respect to the corresponding Drude expressions.

$\sigma_n = \frac{\sigma n}{1+{}^{\omega 2}/_{4\pi 2}}\left(1+\frac{1\omega}{2\tau}\right)$

We have shown the result of real and imaginary part of the complex conductivity $\sigma_n = (\omega + \tau) = \sigma_n' + 2\,\sigma''_n$ verses frequency for a BCS superconductor at $T = 0.5\ T_c$ for different scattering rates τ=0.01πT_4 , τ = 0.1πT_4 and τ = πT_4. Our theoretically evaluated results of (σ_n / σ''_n), as a function of ω/2Δ(T) indicates that the ratio is high for lower values of ω/2Δ(T) but decrease as the value of ω/2Δ(T) increase. The same decrease trend is observed for all the scattering rates. This result also demonstration the increased importance of pair breaking with decreasing τ. We have presented evaluated results of ratio of (σ_n / σ''_n) as a function of ω/2Δ(T) for the same scattering centers. Here also the same trend has been noticed as to for ω/2Δ(T), (σ_n / σ''_n) is large and decrease thereafter in the same fashion.

Keywords :- Unconventional Superconductor, Dynamic Conductivity, BCS Superconductor, Durde Conductivity.

I. INTRODUCTION

The term 'unconventional' superconductor is used here to loosely describe those materials in which neither the origin nor the particular form of the superconducting states has been established with any certainty. There are at least two classes of materials which can thus be termed 'unconventional' : heavy fermion system1 3 and the newly discovered ceramic high Tc superconductors.4 Most of the experimental observations on heavy fermion superconductors1 differ so widely from the predictions of BCS-theory that pairing in some anisotropic state with nodes in the energy gap has been suggested.5 This suggestion is corroborated by microscopic theory of the extent that the strong correlation at the f-atoms disfavour BCS-type pairing. Depending on the model and the approximations used it has been concluded that pairing takes place in 0. anisotropic states, which have the full symmetry of the Fermi surface.5 0 spintriplet p-wave states7 as in superfluid 3He8, or 0. spin-singlet d-wave states9 or more complicated singlet states10 Calculation of various thermal and transport properties for a number of these pair states11-17 have led to the conclusion that superconducting energy gap, which vanishes somewhere on the Fermi surface, does indeed account for all the essential features of the experimental results. Unfortunately, calculated results for all the states investigated are quite similar14 so that the exact pair state cannot be inferred with certainty from the experiments presently available. All that has emerged from these studies so far appears to be a consensus that in UPt3 the energy gap vanishes at lines while in UBe13 it vanishes at points on the Fermi surface. In order to arrive at more definitive conclusions, a more extensive study of anisotropy effects as well as an extension to very low reduced temperatures would be required. Useful information could also be obtained from an investigation of the electromagnetic response which until now has received only scant attention. Through measurements together with a careful theoretical analysis of the dc magnetic field penetration depth in UBe13 are available11. The conclusions with respect to the pair state in UBe13 are based partly on this work.

The results of this study show some features which are clearly in disagreement with BCS theory. For example, the drop in the surface resistance R just below Tc is neither as steep nor as deep24-23, as predicted within the framework of BCS theory.29 Furthermore, for frequencies 0) less than the energy gap. 2A the infrared reflectivity R(w,T = 0) should be 1 according to BCS. 30 With one possible exception31 nobody has observed the predicted high reflectivity. These features may not be intrinsic, but as long as they are present and their origin unexplained there is no justification for the widely held opinion, that the new superconductors are adequately described by BCS theory assuming an isotropic energy gap. In fact, recent determinations of the penetration depth from ac susceptibility measurement32' 35 are indicative of non-BCS behaviour.

MATHEMATICAL FORMULAE USED WITH EVALUATION

In order to study surface resistance, far infrared reflectivity and penetration

depth,- one has to consider a metal bounded by some surface. Even for the simplest possible choice of an infinite plane surface at z = 0 one has to take scattering of charge carriers at this surface into consideration. If the scattering is predominantly diffuse, the calculation of the electromagnetic field inside the metal is very difficult, even in the nearly free electron model35' 30 and it is not clear to us, how these calculations can be generalized to anisotropic superconductors. In the case of specular reflection one can try to restore translational invariance in z direction by filling the empty half-space with the mirror image of the medium actually present.35 Then the components of the electric field E (r, t) and current density J (r, t) have the following symmetry properties with respect to their z-dependence :

$E_{x,y}(z)=E_{x,y}(-z)\ E_z(z) = -E_z(-z)$ (1)

$J_{x,y}(z) = J_{x,y}(-z)\ J_z(-z)\ J_z(z) = -J_z(-z)$ (2)

Since there can be no current through the surface, we must have $J_z(0^-) = J(0+) = 0$ (3)

Unfortunately, the deleterious effects of a surface cannot be evaded so easily, when the system under investigation is anisotropic. Consider, for example, an axial state with its symmetry axis i forming some oblique angle with the surface. At low temperatures, all the thermally excited quasiparticles have momenta nearly (anti) parallel to i. States with specularly reflected momenta, however, cannot be occupied, because they lie inside the energy gap. Hence, the only orientations of the order parameter compatible with the assumption of specular reflection are such that i||zori±z. The same considerations apply to strongly anisotrpic normal metals like Y1 Ba2Cu307_3 where almost all quasiparticle momenta are perpendicular to the (tetragonal) c-axis. If one ignores this point and calculates the electromagnetic response for arbitrary orientations of the anisotropic system with respect to the surface, then (3.2) is violated in general. We discuss physical situations in which (3.2) is fulfilled with sufficient accuracy independent of the directions i or e.

Ambegaokaret.a/.36 have shown that a surface tends to orient an axial state in such a way that i||z. Using the same arguments one would conclude that for a polar state i would be parallel to the surface. There are, of course, a number of competing orientating effects.

All quantities are taken to depend on position parallel to the surface and on time as follows:

$$Ei(r,t) = Ei(z;q_x q_y,w)e^{\,i(qx\,x+qyy-wt)} \qquad (4)$$

This ansatz does not apply to field pattern in resonant cavities, but at microwave frequencies the variation of field parallel to the surface can be neglected when compared with the rapid decrease of field inside the cavity walls. Hence, we can simply put qx = qy = 0 when discussing the low frequency response. Only when the reflectivity of obliquely incident electromagnetic waves with frequencies in the far infrared, infrared or optical regime is studied35 we need to retain the exponential in (3.3). In this case we cannot place any restriction on the components qx, qy of the wave vector of the incoming wave because we prefer to choose the x-axis in such a way that the symmetry axis of the order parameter is always in the xz-plane.

When the Fourier transform with respect to z is taken of the Maxwell Eq.

V X V X E = m^2/C^2 E+ 4ni *m* / C^2 J

inhomogeneous terms appear due to the symmetry requirements. These inhomogeneous terms can be simplified by using at the surface. Cancelling the common factor exp (iqx + iqy y - iwt), we thus find qT denotes the transposed vector and H(0+) is short for H(z = 0+,qx,qy,co). To close the system of equations, the current density induced by the perturbation

$$H_{int} = -e\int d^3rn(r)\Phi(r,t) + \frac{e}{c}\int d^3rj^T(r)A(r,t)$$

is calculated in linear response. Because of the assumption of specular scattering one is effectively dealing with a transnationally invariant system so that the usual linear response theory can be applied without modification

$$J(q,\omega) = e^2\langle[j,n]\rangle(q,\omega)\Phi(q,\omega) \\ -e^2\left\{\langle[j,j^T]\rangle(q,\omega) + \frac{\bar{n}}{m}\right\}\frac{1}{c}A(q,\omega)$$

where n is the average electron density. The scaler potential ®(q,co) has been introduced, because charge fluctuations occur for non-normal incidence.35 For the charge density p(q,co) one finds in linear response

$$\rho(q,\omega) = e^2\langle[n,n]\rangle(q,\omega)\Phi(q,\omega) \\ -e^2\langle[n,j^T]\rangle(q,\omega)\frac{1}{c}A$$

Of course, p should be related to the longitudinal of J through the continuity equation

$$-\omega\rho(q,\omega) + q.J(q,\omega) = 0$$

When p and q.J are expressed through (9) and (8).

This definition is physically very appealing because |||||||f|||| is equal to the total current flowing parallel to the surface,

Note, that only the components Z^A, Zyy, Zxy, Zyx enter 0 the calculation of R. This reflects the fact that losses due to a field component perpendicular to the surface are not included. For certain modes the perpendicular field at the metal surface can be several orders of magnitude larger than the parallel field, which owes its *existence to the finite conductivity. The losses caused by the perpendicular field are none-theiess negligible except in the superconducting state, where they might account for part of the residual surface resistance.42This is notoriously higher when a superconducting cavity is driven in a mode with large perpendicular fields at the cavity walls.42

When the reflectivity for non-normal incidence is studied, the simplest form of the electric field outside A the metal is given in (3.3) with E(z;qx,qy,co) - EVA + EV,clzZ Since V.E(r,t) = 0 everywhere in vacuum, we can eliminate E1 and ER from the curl equation (3.4). Then the continuity conditions (3.1) can be used to obtain the field just inside the conductor whereupon (3.16) can be employed to eliminate the magnetic field. The resulting equations can be simplified by expressing both E^{-A} and E^Ain terms of their components Ep and Es parallel and perpendicular to the plane of incidence. The state of polarization of the incoming wave can then be expressed through the angle <t> between EA and the plane of incidence. It follows that the reflection coefficients.

II. DISCUSSION OF RESULTS

This paper presents a study the electromagnetic response of unconventional superconductor and evaluated the dynamic conductivity of unconventional superconductor. For such superconductor the dynamic conductivity σ depends upon the frequency, temperature, scattering rate, phase shifts, find orientation relative to energy gap. The field orientation is such that $\overline{E}$ points either into the dimension of vanishing energy gap ($\overline{E}_i\hat{1}$ for the polar state and $\overline{E}_i\hat{1}$ for the ABM state) or into the dimension of maximum energy gap. Only the limiting phase shift δ=0 (Born approximation) and $\delta = {}^{\pi}/_{2}$ (unitary limit) have been investigated. The real and imaginary part of σ arc normalised write respect to the corresponding Drude expressions.

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Table T_1

Evaluation of real and imaginary part of the complex conductivity $\sigma_s(\omega,T)=\sigma'_s+i\sigma''_s$ and normalized Drude conductivity $\sigma_n=\sigma'_n+i\sigma''_n$ with different scattering rates $\Gamma T = 0.5\ T_C$

$\omega/2\Delta(T)$	(σ'_s/σ'_n)		
	$\Gamma=0.01\pi T_c$	$\Gamma=0.1\pi T_c$	$\Gamma=\pi T_c$
0	0.052	0.95	0.78
0.1	0.050	0.82	0.65
0.2	0.048	0.73	0.58
0.3	0.037	0.64	0.47
0.4	0.032	0.58	0.32
0.5	0.025	0.52	0.22
0.6	0.020	0.35	0.16
0.7	0.017	0.27	0.10
0.8	0.011	0.18	0.092
0.9	0.009	0.11	0.087
1.0	1.50	0.52	0.87
1.5	1.32	0.67	0.98

Table T_2

Evaluation of ratio of σ''_s/σ''_n as a function of $\omega/2\Delta(T)$ for different scattering centres $\Gamma=0.01\pi T_c$, $\Gamma=0.1\pi T_c$, $\Gamma=\pi T_c$.

$T = 0.5\ T_C$

$\omega/2\Delta(T)$	σ''_s/σ''_n		
	$\Gamma=0.01\pi T_c$	$\Gamma=0.1\pi T_c$	$\Gamma=\pi T_c$
0	1.52	2.80	5.86
0.1	1.50	2.05	4.28
0.2	1.47	1.64	3.75
0.3	1.32	1.47	2.16
0.4	1.30	1.31	1.92
0.5	1.26	1.20	1.58
0.6	1.20	1.14	1.27
0.7	1.18	1.10	1.08
0.8	1.15	1.05	0.95
0.9	1.11	1.00	0.82
1.0	1.0	0.95	0.70
1.1	0.98	0.86	0.62
1.2	0.90	0.70	0.51
1.5	0.86	0.68	0.31

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