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ULTRASONIC ATTENUATION IN HEAVY FERMION SUPERCONDUCTORS

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The large effective electron mass in the heavy fermion superconductors UPt_3 and UBe_{13} can produce peaks and other features in the temperature and magnetic field dependent sound attenuation.

1. INTRODUCTION

Experimental measurements of longitudinal ultrasonic attenuation $\alpha(T,H)$ in the heavy fermion superconductors UPt_3 and UBe_{13} have revealed a variety of peaks and other features in $\alpha(T,H)$ in zero and finite magnetic fields (H)[1 2]. Theoretical proposals to explain these unconventional results have included collective modes and, in the case of the $H \neq 0$ observations, phase transitions involving the magnetic vortex lattice of unconventional, anisotropic superconducting order parameters[2].

However peaks in $\alpha(T,H)$ in both zero and non-zero magnetic fields can arise due to the high effective mass m_e^* of the superconducting charge carriers in these compounds.

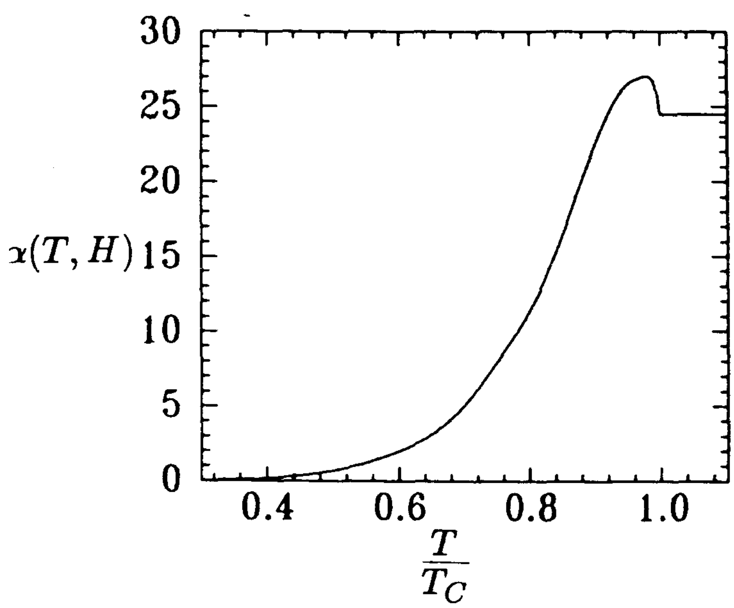

Fig. (1) $\alpha(T,H=0)$ for an isotropic order parameter with $ql = 60.0$ and $\omega\tau = 40.0$. $\alpha(T,H)$ is in units of $nm_e^*/\rho s\tau$.

2. THEORETICAL RESULTS

2.1. $\alpha(T,H)$ for $H = 0$

The dynamical conductivities $\sigma(q,\omega)$ and $\sigma^I(q,\omega)$ which describe the response of the heavy electron gas to electromagnetic fields determine $\alpha(T,H)$[1]. Here $\omega = sq$ where s is the sound velocity and $\sigma^I(q,\omega)$ arises due to impurities in the oscillating lattice. Thus

$$\alpha(T,H=0) = \frac{nm_e^*}{\rho s\tau}\mathrm{Real}\left(\frac{\sigma_o - \sigma^I}{\sigma}\right) \qquad (1)$$

where $\sigma_o = ne^2\tau/m_e^*$. τ is the normal state lifetime due to impurity scattering, ρ is the ionic density and n is the electron concentration.

A large m_e^* implies that s/v_F (v_F is the Fermi velocity) is much greater than the typical value of 0.01 with values of 0.1 or greater not unreasonable in the heavy fermion

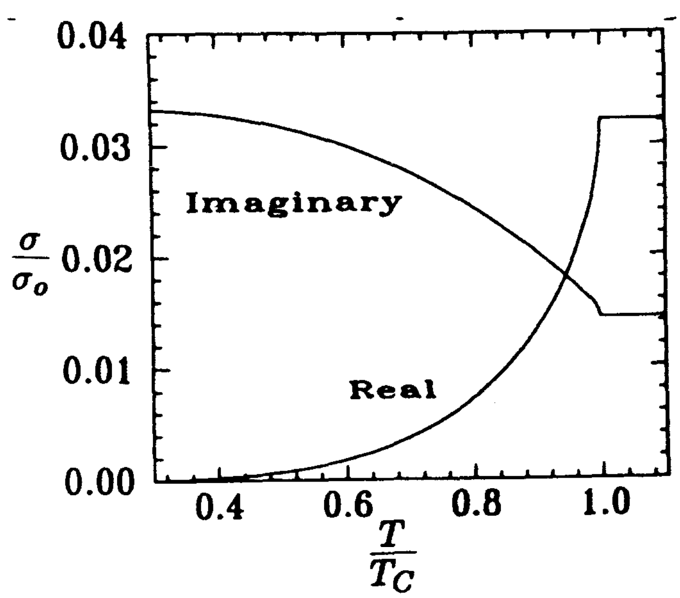

Fig. (2) Real and imaginary parts of the conductivity $\sigma(q,\omega)$ corresponding to Fig.(1).

compounds [3]. The ratio $s/v_F = \omega\tau/ql$, where l is the mean free path, plays an important role in determining $\alpha(T, H = 0)$ via $\sigma(q,\omega)$ and $\sigma^I(q,\omega)$ [3] . Conventionally, in the normal state, Real$[\sigma(q,\omega)] \ll$ Im$[\sigma(q,\omega)]$. In the heavy fermion case, where $s/v_F \leq 1$, this inequality is reversed. The resulting temperature dependence of $\alpha(T, H = 0)$ for a BCS isotropic superconductor and the corresponding magnitudes of the real and imaginary parts of the conductivity $\sigma(q,\omega)$ for $ql = 60.0$ and $\omega\tau = 40.0$ are shown in Figures (1) and (2) respectively. A peak occurs in $\alpha(T, H = 0)$ at the temperature at which the real and imaginary parts of $\sigma(q,\omega)$ cross just below T_C. Peaks in $\alpha(T, H = 0)$ are also present in the hydrodynamic limit $ql \leq 1$ where the interplay of $\sigma(q,\omega)$ and $\sigma^I(q,\omega)$ has to be taken into account carefully. However the role of s/v_F is as central as for the $ql \gg 1$ case [3] . Similar $\alpha(T, H)$ occur for anisotropic superconducting states for the same underlying reason. Thus the experimentally observed peaks in $\alpha(T, H = 0)$ in UPt_3 and UBe_{13} just below T_C are not firm evidence of unconventional superconductivity such as anisotropic order parameters or unusual modes of such order parameters. They may be merely more confirmation that the charge carriers going superconducting have a high effective mass.

2.2. $\alpha(T, H)$ for $H \neq 0$

Normal state ultrasonic attenuation in a finite magnetic field can display peaks when $\omega = n\omega_c$, where ω_c is the cyclotron frequency $eH/m_e^* c$ [4] . Some new results are presented here for a superconducting state with a line of zeroes on the Fermi surface and a sound wavevector q at 90^o relative to the applied magnetic field H.

Firstly the theoretical peak in $\alpha(T, H)$ [1] at the normal-superconducting phase boundary for $H = 0$ can be suppressed to zero for T/T_C less than one and H varying from above to below H_{C2}. This is in accord with experiments on UPt_3 where the small zero field peak is eliminated in the presence of applied magnetic fields.

One interesting and possibly significant observation about the experimental work [2] on $\alpha(T, H)$ in finite magnetic fields below H_{C2} in UPt_3 is, that at the magnetic field strengths where small features are observed in $\alpha(T, H)$ (typically $H \simeq 0.5 H_{C2}$), ω and ω_c are comparable. Both frequencies are in the 10^2MHz range. This occurs because m_e^* for UPt_3 is about 10^2 times the bare electronic mass. Theoretical results for $\alpha(T, H)$ are plotted in Figure (3) for $T/T_C = 0.4$. Parameters are chosen so that $\omega = \omega_c$ at $H = 2/3 H_{C2}$. Broadening due impurity scattering alters the simple resonance condition mentioned above where features can be observed in the attenuation curves. The present calculation is not meant to be a quantitiative comparison with data since a spherical Fermi surface has been assumed. However it is possible that the small features in finite field experiments on UPt_3 are again arising from the high effective mass m_e^* rather than an unusual phase transition involving exotic superconducting phases. More detailed calculations on this will be published elsewhere.

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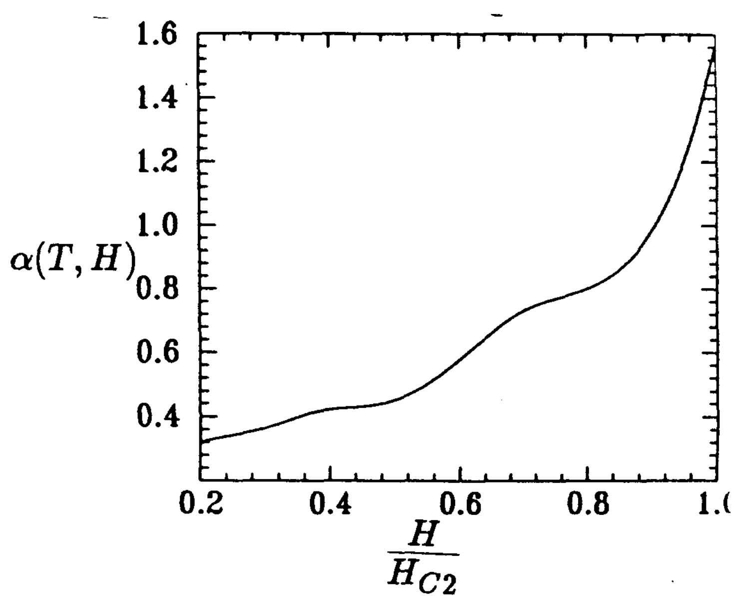

Fig. (3) $\alpha(T, H)$ for an order parameter with a line of zeroes on the fermi surface. q is at 90^o to H. $\omega\tau = 2.0$ and $ql = 4.0$. $\alpha(T, H)$ is in units of $nm_e^*/\rho s\tau$.

References

[1] L. Coffey, Phys. Rev. B35 (1987) 8440. This paper contains references to recent experiments.

[2] A. Schenstrom, M-F. Xu, Y. Hong, D. Bein, M. Levy. B.K. Sarma, S. Adenwalla, Z. Zhao, T. Tokuyasu. D.W. Hess, J.B. Ketterson, J.A. Sauls. and D.G. Hinks, Phys. Rev. Lett. 62 (1989) 332.

[3] L. Coffey, Phys. Rev. B40 (1989) in press.

[4] M.H. Cohen, M.J.Harrison and W.A. Harrison, Phys. Rev. 117 (1960) 937