ON THE PHENOMENOLOGICAL APPROACH TO THE HIGH TEMPERATURE SUPERCONDUCTORS

B.R. Alascio and C.R. Proetto

Centro Atómico Bariloche, 8400 S.C. de Bariloche, Río Negro, Argentina

(Received

A model where a system of paired electrons interacts with a band of normal electrons is studied. It is shown that this model leads quite naturally to a one particle self-energy completely equivalent to the one recently proposed (Varma et al., Phys.Rev.Lett. 63, 1996 (1989)) to explain the anomalous properties of the normal state of Cu-O high temperature superconductors.

Varma et al.[1] have recently proposed a phenomenological approach to the high temperature superconducting materials.

In their approach these materials are characterized by a set of "universal anomalies" in their normal state properties. These anomalies find a common denominator through the introduction of an ansatz polarizability, which in turn leads to a particular one-particle self-energy.

The special feature of this particular self-energy is that at T=0 its imaginary part takes a non-Fermi liquid V-shaped form at the Fermi level (see full line (a) in Fig. 1). At T≠0 the V-shaped curve truncates at $\omega=T$ (see full lines (b) and (c) in Fig. 1).

Quite a number of properties if the High Tc materials derive from this self-energy.

We want to show here that the self-energy proposed in Ref. 1 arises quite naturally from the assumption that a band of negative U states crosses the Fermi level of a normal Fermi liquid.

Several authors[2]-[4] have modeled such situation where a system of paired electrons interacts with a band of normal electrons. They conclude that the model could apply to high temperature superconductors.

The corresponding Hamiltonian can be defined as :

$$H = \sum_{\vec{k}\sigma} \varepsilon_{\vec{k}} c^{+}_{\vec{k}\sigma} c_{\vec{k}\sigma} + \sum_{i,\sigma} \left[E_i d^{+}_{i\sigma} d_{i\sigma} - (U_i/2) d^{+}_{i\sigma} d_{i\sigma} d^{+}_{i\bar{\sigma}} d_{i\bar{\sigma}} \right] + \tag{1}$$

$$V \sum_{i} \left[c^{+}_{i\uparrow} c^{+}_{i\downarrow} d_{i\downarrow} d_{i\uparrow} + d^{+}_{i\uparrow} d^{+}_{i\downarrow} c_{i\downarrow} c_{i\uparrow} \right]$$

where $c^{+}_{\vec{k}\sigma}$, $c^{+}_{i\sigma}$ denote the electron operators of the single band subsystem, $\vec{k}$ and i refer either momentum of their site and σ denotes the electron spin. $d^{+}_{i\sigma}$, $d_{i\sigma}$ are the creation and anihilation operators of paired electrons which sense an effective on-site attractive interaction U_i ($U_i > 0$).

The assumption that U_i is large and attractive is implicit in the exclusion of one particle mixing terms in equation (1).

Consider now the second order (in V) contributions to the self-energy Σ; assuming a continuous distribution $\rho_b(\Delta_i)$ of energies per particle $\Delta_i = (2E_i - U_i)/2$, we obtain strighforwardly

$$-\mathrm{Im}\ \Sigma(\omega) = \frac{\hbar}{\tau(\omega)} = \tag{2}$$

$$\frac{\pi V^2}{N}\,\rho_c \int \rho_b(\Delta_1)\,\frac{\cosh(\omega/2T)}{\cosh(\Delta_1/T)\cosh\left[(\Delta_1-\omega/2)/T\right]}\,d\Delta_1$$

where $\tau(\omega)$ is the relaxation time, N the number of sites in the cristal, and ρ_c the density of band states per site.[5] This result was first obtained by Eliashberg[5].

To show the similarity between the proposed Im $\Sigma(\omega)$ and the result corresponding to equation (2) we evaluate this equation for a constant density of paired states extending from -A to B. We also assume a constant density of band states extending between -W and W. The energies involved are schematized in Fig.2.

With this energy scheme we obtain

$$-\mathrm{Im}\ \Sigma(\omega) = \frac{\hbar}{\tau(\omega)} = \tag{3}$$

$$\frac{c}{2}\,T\coth(\omega/2T)\,\ell n\left|\frac{1+\tanh(A/2T)\tanh(\omega/2T)}{1-\tanh(B/2T)\tanh(\omega/2T)}\right|$$

where $c = 2\pi V^2\rho_c\rho_b/\hbar N$.

The curves for Im $\Sigma(\omega)$ at different temperatures are compared with those proposed by Varma et al. in Fig.1.

From Im $\Sigma(\omega)$ one can obtain the real part of the self-energy (Re $\Sigma(\omega)$) using the Kramers-Kroning relations. As pointed out in Ref.(1), the critical dependence of Re $\Sigma(\omega)$ on ω at $\omega=0$ is a direct consequence of the form Im $\Sigma(\omega)$, and leads to the "marginal Fermi liquid" concept. However, the absolute value of Re $\Sigma(\omega)$ near $\omega=0$ can result from other process. In Fig.3 we compare Re $\Sigma(\omega)$ obtained from equation (3) to the one obtained from the phenomenological approach (full lines in Fig.1).

In conclusion, we have shown that the phenomenological form of the one particle self-energy proposed by the authors of Ref.1 arises naturally from the assumption that a band of paired states crosses the Fermi energy of a normal Fermi liquid.

REFERENCES

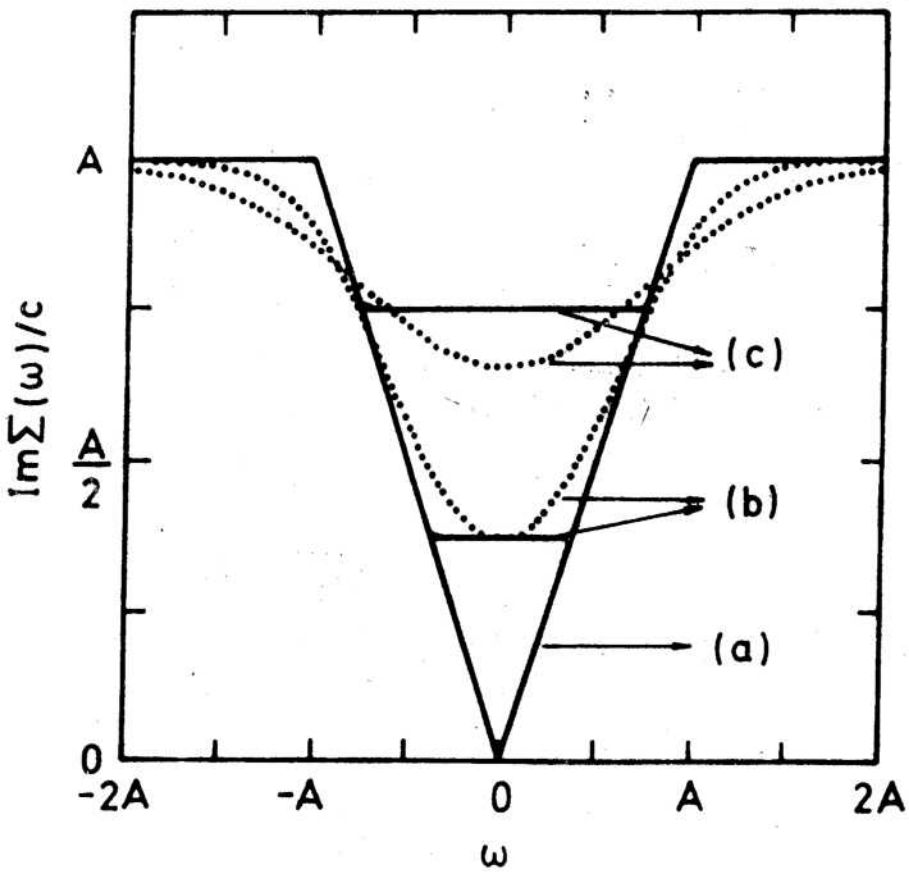
1) C.M. Varma, P.B. Littlewood, S. Schmitt-Rink, E. Abrahams, and A.E. Ruckenstein, Phys.Rev. Lett. 63, 1996 (1989).
2) R.Micnas, J. Ranninger, and S. Robaszkiewicz, to be published in Rev.Mod.Phys. (January 1990) and references therein.
3) L. Ioffe, A.I. Larkin, Yu N. Ovchinnikov, and L. Yu. To be published in "Strongly Correlated Electron Systems", ed. by G. Baskaran, A.E. Ruckenstein, E. Tossatti, and Yu Lu, World Sci.Publ.Co., Singapore, 1989.
4) I.O. Kulik, Int.J.Mod.Phys.B 2, 851 (1988).
5) G.M. Eliashberg, Pisma Zh.Eksp.Teor. 46, 94 (1987).

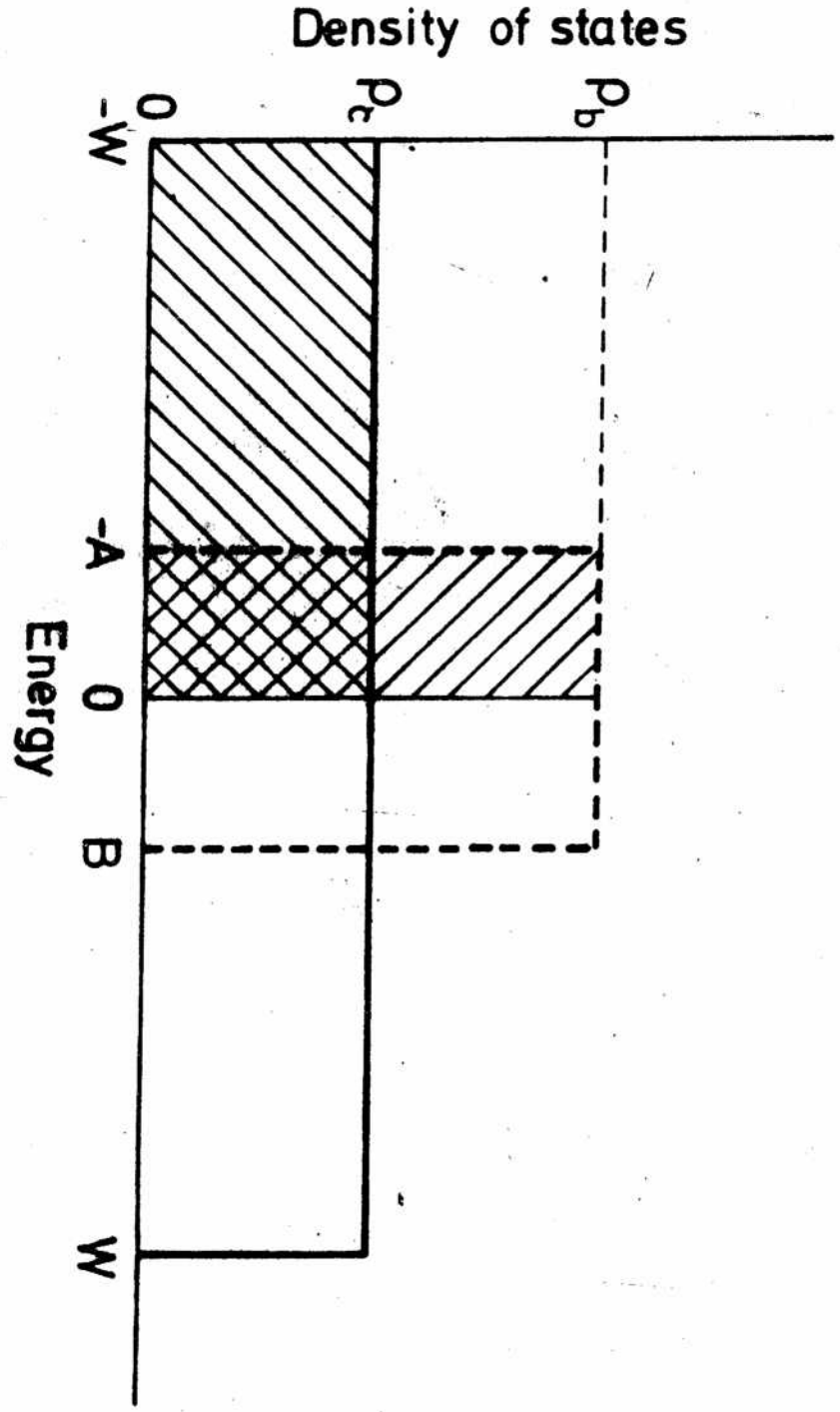
FIGURE CAPTIONS

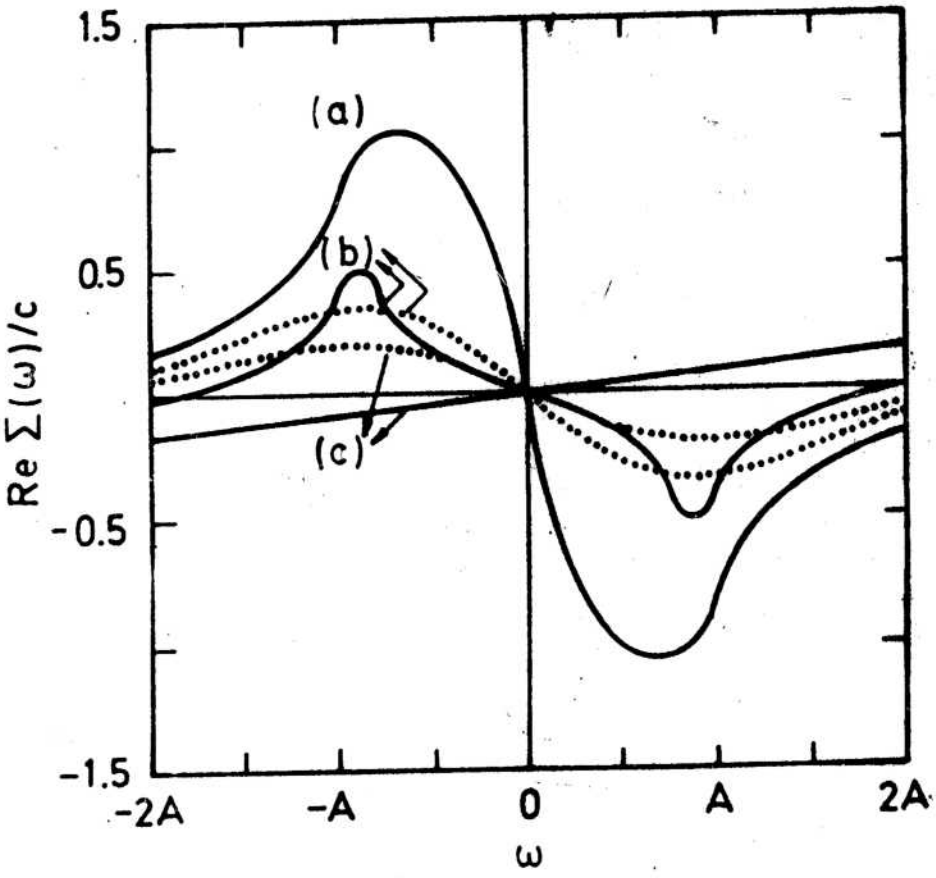
Figure 1: Imaginary part of the self-energy (Im $\Sigma(\omega)$) as function of frequency (ω). Full lines: phenomenological approach (Ref.1), dotted lines: equation (3).
(a) T = 0, (b) T = 0.375 A, (c) T = 0.75 A.

Figure 2: Schematic drawing of the band configurations used in the evaluation of equation (2). ρ_c corresponds to the density of states associated with the single electrons (extendings from -W to W), while ρ_b corresponds to the density of states of paired electrons (extending from -A to B).

Figure 3: Real part of the self-energy (Re $\Sigma(\omega)$) as function of frequency (ω). Full lines: phenomenological approach (Ref. (1)), dotted lines: this work.
(a) T = 0, (b) T = 0.75 A, (c) T = A.


A
A/2
0
Im Σ(ω)/c
(c)
(b)
(a)
-2A
-A
0
A
2A
ω


Density of states
0
ρ_c
ρ_b
-W
-A
0
B
W
Energy


1.5
0.5
-0.5
-1.5
Re Σ(ω)/c
(a)
(b)
(c)
-2A
-A
0
A
2A
ω