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Superconductors that change color when they become superconducting

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We consider models of superconductivity where pairing originates in gain of kinetic rather than potential energy of the carriers. In such systems, a change in the frequency-dependent conductivity occurs at frequencies much higher than the scale set by the superconducting energy gap. This property follows from a general sum-rule argument. To clarify the physical origin of this spectral weight transfer we consider several microscopic hamiltonians that give rise to an effective hamiltonian with a kinetic pairing interaction. These models describe small polarons with a non-linear interaction with a background degree of freedom, that gives rise to an effective mass enhancement that depends on the local charge occupation. Superconductivity in these models can be understood as arising from the partial "undressing" of carriers that occurs upon pairing. The same "undressing" occurs in these systems upon doping in the normal state, which causes superconductivity to disappear at high doping. Optical conductivity is calculated for one of the model hamiltonians to illustrate the effect. It is suggested that some of the observed phenomenology of high-T_c oxide superconductors resembles the behavior of the class of superconductors discussed here.

1. Introduction

Conventional BCS superconductors [1] are expected to change their response to electromagnetic fields only for field frequencies of order of or smaller than twice the superconducting energy gap [2]. This energy range, which is also of the order of the critical temperature, corresponds to the far infrared/microwave regime in conventional superconductors. In that frequency range the electromagnetic field cannot excite electrons across the superconducting energy gap, and the optical absorption is reduced compared to the normal state [3]. For frequencies much higher than the superconducting energy gap, no change in optical absorption is predicted within conventional BCS theory [1,2].

It is interesting to note, however, that before the advent of BCS theory various experimental attempts were made [4] to detect changes in optical properties of superconductors at frequencies ranging from infrared to visible. The expectation was that superconductors, by analogy with good metals, might be particularly good reflectors of high-frequency radiation. No effect was found at the time within the available accuracy.

In this paper we discuss a class of superconductors where a change in high-frequency electromagnetic response *is* expected to occur upon entering the superconducting state. In these superconductors pairing originates in a gain in *kinetic* rather than potential energy of the carriers. The resulting increase in low-energy electromagnetic response has as a necessary consequence a decrease in optical absorption at high frequencies. This conservation of oscillator strength follows from a general sum-rule argument [5].

The purpose of this paper is to shed light into the microscopic origin of this spectral weight transfer by considering various simplified microscopic hamiltonians. No attempt is made to make these hamiltonians particularly realistic, instead they are taken as simple as possible to exhibit the essential physics. We consider a generalized Holstein model [6,7], a model of electrons interacting with spin degrees of freedom [8,9], and a purely electronic model with two orbitals per site [10,11]. The common aspect to these hamiltonians is that a non-linear interaction