Specific heat of d-wave pairing in cuprate superconductors

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Sergei Kruchinin
National Academy of Sciences of Ukraine

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Specific heat of d-wave pairing in cuprate superconductors

Sergei P. Kruchinin[a] and Stamatis K. Patapis[b]

[a]Bogolyubov Institute for Theoretical Physics, 252143, Kiev,
Metrologicheskaya 14-b, Ukraine

[b]Department of Physics, Solid State Physics Section, University of Athens,
Panepistimiopolis, GR 157 84, Zografos, Greece

The mechanism of d-pairing with account of antiferromagnetic spin fluctuations was considered. It has been shown that the temperature dependence of thermal capacity corresponds to d-pairing.

1. INTRODUCTION

Some recent papers consider the mechanism of antiferromagnetic spin fluctuations [1,2]. Electron scattering on these fluctuations may cause the electron pairing with d-symmetry. Spin fluctuations play an important role in superconductors with heavy fermions [3]. The aim of this work is to calculate the specific heat of d-wave pairing in cuprate superconductors.

2. RESULTS

The antiferromagnetic spin fluctuations which result in d-pairing in cuprate superconduction are described by the Lagrangian [4]:

$$L = \sum_{\vec{n}} \psi^+_\alpha(\vec{n})(\frac{\partial}{\partial\tau} - \mu)\psi_\alpha(\vec{n}) - t\sum_{\vec{n},\vec{p}} \psi^+_\alpha(\vec{n})\psi_\alpha(\vec{n}+\vec{p})$$

$$+g\sum_{\vec{n}} \psi^+_\alpha(\vec{n}) \left(\frac{\sigma^i}{2}\right)_{\alpha,\beta} \psi_\beta(\vec{n})S_i(\vec{n}) +$$

$$+\frac{1}{2}\sum_{\vec{n}\vec{m}} S_i(\vec{n})\chi^{-1}_{ij}(\vec{n},\vec{m})S_j(\vec{m}),$$

where the summation is over all knots of infinite lattice, $\vec{p}$ ia a unit vecor, which connects the neighboring knots, μ is a chemical potential, g is the interaction constant, $\sigma_{\alpha,\beta}$ is the Pauli matrix, $S_i(\vec{n})$ is the operator of spin fluctuations in lattice representation, $\psi^+_\alpha(\vec{n})$ is the operator of an electron creation on n-th site, and $\psi_\alpha(n)$ is the operator of a hole creation on n-th site, α is a spin projection, $\chi_{ij}(\vec{n},\vec{m})$ is the spin correlation function [1], t is a band halfwidth It is convinient to use the formalism of continual integration for Fermi systems. The big statistical sum can be written in the form of functional integral [4,5]:

$$e^{-\beta\Omega} = N\int \prod_{\vec{m}} dS_i(\vec{n})d\psi^+_\alpha(\vec{n},\tau)d\psi_\alpha(\vec{n},\tau)$$

$$\cdot\exp\left\{-\int_0^\beta d\tau L(\tau)\right\},$$

where $\beta = 1/kT$, N ia a normalization multiplier.

In the weak coupling approximation (lowest order in g^2) we have calculated the thermodynamic potential:

$$\Omega(\Delta) = V\int \frac{d^2k}{(2\pi)^2}\left\{-\frac{2}{\beta}\ln\frac{\mathrm{ch}\frac{\beta}{2}(\sqrt{(\varepsilon(\vec{k})-\mu)^2+\Delta(\vec{k})^2})}{\mathrm{ch}\frac{\beta\varepsilon}{2}} + \right.$$

$$\left. + \frac{\Delta(\vec{k})^2}{2\sqrt{(\varepsilon(\vec{k})-\mu)^2+\Delta(\vec{k})^2}}\mathrm{th}\frac{\sqrt{(\varepsilon(\vec{k})-\mu)^2+\Delta(\vec{k})^2}}{2}\right\}.$$

Here V is a two dimensional volume (the area of the cuprate layered), $\Delta(\vec{k})$ is a superconductivity gap, $\vec{k}$ is a momentum of an electron, $\varepsilon(\vec{k})$ describes the spectrum of two-dimensional electron. The heat capacity was calculated using the formula:

$$C = -T\frac{\partial^2\Omega}{\partial T^2}.$$

We have done the computer calculations for $YBa_2Cu_3O_{6.63}$. The equation for the gap Δ was obtained in Refs. [2,4]. The gap value depends on the spin correlation function. Data needed for the definition of the correlator were taken from [2]. Tha numerical calculations show the linear behaviour of the ratio of the specific heat to temperature, C/T, in the range from zero to critical temperature.

3. DISCUSSION

In the paper [6] the specific heat in the superconducting state of the heavy Fermion considering all symmetry allowed gap functions was modelled. It was shown that the d-symmetry resulted in the linear dependence of C/T on temperature. s-symmetry is connected with nonlinear dependence of this value on temperature. The similiar rezult was obtained in this paper for antiferromagnetic spin fluctuations in cuprate superconductors. The linear dependence of C/T on temperature has been observed in experintantal work [7] for YBaCuO systems.

4. CONCLUSIONS

The problem of the definition of the gap symmetry in cuprate superconductors in the main one [8-11]. The achieved temperature dependence of the antiferromagnetic spin fluctuations corresponds to d-pairing. The present calculations may be the additional test in the definition of the symmetry of the gap in the cuprate superconductors.

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