New findings about high-temperature super-conductors

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Abstract

Bozovic et al have reported rather interesting new findings about high T_c super-conductivity: for over-critical doping the critical temperature is proportional to the density of what is identified as Cooper pairs of electronic super-fluid. Combined with the earlier findings that super-conductivity is lost - not by splitting of Cooper pairs - but by reduction of the scale of quantum coherence, and that below minimal doping fraction critical temperature goes abruptly to zero, allows to add details to the earlier TGD inspired model of high T_c super-conductivity. The super-conductivity would be indeed lost by the reconnection of flattened square shaped long flux loops to shorter loops of pseudogap phase. Quantum coherence would be reduced to smaller scale as h_{eff} is reduced. Transversal flux tube "sound waves" would induce the reconnections. Electrons at flux loops would stabilize them by contributing to the energy density and thus to the inertia increasing the string tension so that the average amplitude squared of oscillations is reduced and critical temperature increases with electron density.

1 Introduction

A popular article in Phys.org (see `http://tinyurl.com/htr2qjj`) tells about new interesting results about high T_c superconductivity. Bozovic et al have published in Nature an article titled "*Dependence of the critical temperature in overdoped copper oxides on superfluid density*" (see `http://tinyurl.com/gqo9j67`) [D2]. The abstract of the article gives first glimpse about the work.

> *The physics of underdoped copper oxide superconductors, including the pseudogap, spin and charge ordering and their relation to superconductivity is intensely debated. The overdoped copper oxides are perceived as simpler, with strongly correlated fermion physics evolving smoothly into the conventional BardeenCooperSchrieffer behaviour. Pioneering studies on a few overdoped samples indicated that the superfluid density was much lower than expected, but this was attributed to pair-breaking, disorder and phase separation. Here we report the way in which the magnetic penetration depth and the phase stiffness depend on temperature and doping by investigating the entire overdoped side of the La2xSrxCuO4 phase diagram. We measured the absolute values of the magnetic penetration depth and the phase stiffness to an accuracy of one per cent in thousands of samples; the large statistics reveal clear trends and intrinsic properties. The films are homogeneous; variations in the critical superconducting temperature within a film are very small (less than one kelvin). At every level of doping the phase stiffness decreases linearly with temperature. The dependence of the zero-temperature phase stiffness on the critical superconducting temperature is generally linear, but with an offset; however, close to the origin this dependence becomes parabolic. This scaling law is incompatible with the standard BardeenCooperSchrieffer description.*

I do my best in order to understand what this says. The Wikipedia article (see `http://tinyurl.com/b25sucr`) helps to get overall view about high T_c superconductivity. The Phys.org article (see `http://tinyurl.com/htr2qjj`) gives first clues in attempts to understand what the abstract says. The earlier article of Bozovic et al (see `http://tinyurl.com/hk88h5w`) [D1] stating that the loss of super-conductivity does not mean splitting of Cooper pairs but loss of quantum coherence or rather its reduction to shorter length scale gives additional insights.

In the following I proceed by self-Socratean method by making questions and bringing in the TGD view based on quantum criticality and magnetic flux tube pairs as carriers of members of Cooper pairs responsible for the supra current.

2 Basic notions

I try first to understand the notions of doping and phase stiffness.

1. In the work under discussion [D2] overdoped cuprate superconductors were studied. Doping by holes and electrons is possible. Underdoped superconductors are studied and are not well-understood. Superconductivity appears in some range for the values of the doping fraction: the minimal doping is typically something like .05 for holes and .2 for electrons from the diagram of Wikipedia article.

   "Overdoping" is achieved by the addition of strontium atoms as impurities. It had been already known that overdoping induces a reduction of the density of electron pairs and that critical temperature is reduced as a consequence. In the experiments discussed the critical temperature was found to depend linearly on the density of what was identified as super-fluid electron pairs linearly and going to zero as the doping fraction increases. In TGD pairs would correspond to small scale super-conductivity.

   There is also the notion of self-doping, see the popular article titled "*Self-doping may be the key to superconductivity in room temperature*" at `http://tinyurl.com/jxrdagm` telling about the article of Magnuson et al [D3] (see `http://tinyurl.com/zvfhqu2`). There are mysterious chains between the lattice planes of cuprate carrying negative charge. Self doping means that the system itself generates them and controls the charge density at them. Could these chains be associated with the flux tube pairs carrying the Cooper pairs in TGD framework?

2. Phase stiffness refers to the phase of a complex order parameter (see the article "*Weak phase stiffness and nature of the quantum critical point in underdoped cuprates*" of Yildrim and Ku at `http://arxiv.org/abs/1302.7317`), which might correspond to that assignable to the short range super-conductivity (or superfluidity as authors identify it). One poses twisted boundary conditions forcing the phase to vary spatially. How this is done, I do not understand.

   The phase stiffness corresponds to energy density forced by these boundary conditions. In lowest order approximation energy density is proportional to the square of the gradient of the phase and coefficient is analogous to string tension. This parameter is proportional the density of Cooper pairs theoretically. The strange thing is that phase stiffness goes to zero below the minimal doping rather than going to zero smoothly. In overdoped region the phase stiffness at zero temperature limit was found to depend linearly on the critical temperature.

3 TGD based model for the findings

TGD inspired model for high T_c superconductivity and bio-superconductvity have been developed gradually during two decades [**?**, K1, K2, K3, K4] [L1, L2]. The new results allow to add new details to this model, in particular to the understanding of what happens when the superconductivity is lost.

1. The popular article says that the critical temperature is controlled by the 2-dimensional density of electron pairs identified as super-fluid Cooper pairs. They would correspond to the so called pseudogap phase. An important point is that super conductivity is not lost due to the breaking of Cooper pairs as in the ordinary super-conductivity but due to too small value of the density of electron pairs: this is also the TGD view. In an earlier work to which Bojovic also contributed it is claimed that super-conductivity is lost due to the loss of quantum coherence rather than splitting of Cooper pairs [D1] (see `http://tinyurl.com/zmbeynz`).

Both these findings conform with the TGD view that transition to super-conductivity means a phase transition increasing the value of h_{eff} increasing the range of quantum coherence scaling like h_{eff}. Cooper pairs exist also in pseudogap phase and can have non-standard value of h_{eff} but the closed flattened square shaped flux loops along which the members of pairs flow are too short to give rise to super-conductivity in macroscopic scales. in TGD framework the electron super-fluid about which the article talks would correspond to short scale superconductivity.

The density of Cooper pairs for small value of h_{eff} identified by authors as super-fluid carriers would be the critical quantity: for some range of this parameter the h_{eff} increasing phase transition would take place. This range would in turn correspond to a range for the energy assignable to the pair if the energy is proportional to 2-D Fermi energy.

2. This allows to consider TGD based model of high T_c super-conductivity in which Cooper pairs have their members at parallel magnetic flux tubes closing to a loop and carrying magnetic fluxes in opposite direction in the case of antiferromagnet. In pseudogap phase the pairs would have their members at the flux tubes with opposite spin directions. In the phase transition to superconductivity the value of h_{eff} would increase and the flux tubes would reconnect to much longer flux tubes and macroscopic super current would flow.

3. What happens in the phase transition increasing h_{eff} giving rise to superconductivity in macroscale? The lengths of closed flux loops are scaled up in reconnection. Longitudinal energy is not affected. It seems that the transversal distances between flux tubes cannot change.

   What happens to the strength of magnetic field? Is should be reduced to keep cyclotron energy proportional to $h_{eff}B$ constant? For monopole flux, flux conservation requires that magnetic flux BS does not change so that the area S of the flux tube would scale like h_{eff}. That cyclotron energy is not changed at all would conform with the intuition about quantum criticality.

4. Why the phase trasition to larger h_{eff} phase occurs only above the critical temperature? Why these flux loops are unstable against reconnection above critical temperature? Cooper pairs do not split but reconnection splitting long closed flux loop to a sequence of shorter ones takes place.

   Some energy assignable to large h_{eff} flux tubes is reduced below the thermal energy above critical temperature and a transition to small h_{eff} phase. In reconnection process the parallel flux tubes with opposite fluxes touch each other. This touching occurs if there are oscillations of flux tubes in transversal direction analogous to transversal sound waves.

   Does the average amplitude of transversal "sound waves" become so large above critical temperature that reconnections occur? This brings in mind ordinary BSC superconductivity in which phonon-electron interaction makes possible formation of Cooper pairs as bound states. Phonons for the ordinary super-conductvity however corresponds to lattice oscillations and make superconductivity possible. Now just the opposite happens.

5. What the proportionality of T_c to the density of small Cooper pairs could mean? The energy of transversal phonon is proportional to its amplitude squared. If the amplitude and thus energy is above critical value the reconnection occurs.

   Why the critical thermal energy increases with the density of small Cooper pairs? Does the presence of Cooper pairs stabilize the flux tubes: for too small density flux tubes are not stable since their string tension is too low and they are too soft and have large amplitude of thermal fluctuations.

   Does the presence of Cooper pairs increase the inertia of flux tubes and therefore their string tension? The hermal energy of stringy sound waves proportional to critical temperature becomes proportional to electron density if the electron density dominates in string tension. This would explain also the lower critical value for the doping fraction. Below it flux tubes become so soft that reconnection occurs too fast to allow super-conductivity at all. Above pseudogap temperature even the short loops would become unstable.

What we have obtained? In TGD framework the super-conductivity is not spoiled by the splitting of Cooper pairs but by the reconnection of flattened square shaped long flux loops. Superconductivity is lost by the reconnection of flattened square shaped long flux loops to shorter loops of pseudogap phase, which is super-conducting but in smaller scale. Transversal flux tube "sound waves" induce the reconnections. Electrons at flux tubes stabilize them by contributing to the energy density and thus to the inertia increasing the string tension so that the average amplitude squared of oscillations is reduced and critical temperature increases with electron density.

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