行政院國家科學委員會補助專題研究計畫成果報告

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※ 在高溫超導體的漩渦晶格的結構，相變和 fluctuations。 ※

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計畫類別：x 個別型計畫　□整合型計畫

計畫編號 NSC ~~90~~-2112-M-009-072

執行期間：87 年 08 月 01 日至 90 年 07 月 31 日

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中文摘要,緣由與目的

這項研究計劃包含以下五個相關的主題：

1． 在無 s 波超導體的漩渦晶格結構，磁性和 transport 。

我將採用 d+s 和 s+id 波的混合（其描述高溫超導）其發展去年的計畫而 p 波（其描述 heavy fermion, 和目前所發現的超導 Sr2RuO4,..）有效 Ginzburg-Landau 方程式來研究漩窩晶格結構。特別地我要研究 rotation 和 time reversal 對稱破壞。我將採用於時間有關的 GL 方程式來計算非線性的 transport (direct 和 Hall)。對 p 波而言 spontaneous vortex 狀態和磁化將會被確定。

2． 在高溫超導體的 fluctuations 和 criticality。

我將採用在 d 波超導體的雜質的 Cooper pair breaking 能力來解釋在電物系所得到的令人驚奇的 fluctuation conductivity 實驗結果。同時的我計畫以在高溫超導相變的問題上做研究。

3． 在 高溫超導體的 structural（結構）相變。

去年的研究結果開放了新的研究領域：body centered rectangular Abrikosov 晶格變成 square。我希望對能這個新的現象做進一步的探討。

4． Abrikosov 晶格的融化。一般融化現象的理論。

這一年來我發展了處理 Abrikosov 晶格融化的方法。我把這種方法將推廣到 d 波超導，超導薄膜和 organic 超導。用我過去在 "dusty plasma" 和 Abrikosov 晶格的融化的研究所得到的經驗，將試

試看做為一般融化現象的理論。重要的概念是，四維空間的融化相變變成一個二階 （second order）相變。

關鍵詞：高溫超導，超導漩渦，融化，p,d — 波 (p,d wave)，非微擾現象

Abstract and goals

The proposal will contain following (related) projects.

1. ***Flux lattice structure, magnetic properties and transport in p and p- wave superconductors.***

I will use an effective Ginzburg-Landau equations for s-d and s+id mixing (describing high Tc superconductors) developed in the previous proposal and the p wave ones derived recently (describing "heavy fermion" and some recently discovered superconductors like to determine vortex and the vortex lattice structure. In particular I will examine the breaking of rotational and time reversal symmetries effects. Time dependent GL equations will be used to calculate the nonlinear transport (direct and Hall). For p-wave the spontaneous vortex state and magnetization will be determined.

2. ***Fluctuations and criticality in high Tc superconductors.***

I will try to explain the surprising data obtained by our group at NCTU on fluctuation conductivity using the idea of nonzero critical coupling for d-wave superconductors in the presence of nonmagnetic impurities. I plan to determine the universality class of the quantum phase transition as superconductivity disappears.

3. ***Structural phase transitions in high Tc superconductors.***

Additional area of research was opened as a result of the previous project: there is transition from body centered rectangular to square lattice in d – wave superconductors. I will construct the theory of this novel phenomenon.

4. ***Flux lattice melting. General theory of melting.***

In the previous proposal I developed the nonperturbative method to describe melting of the Abrikosov lattice starting from the s wave GL free energy. I will generalize the method to the d-wave superconductors, to thin films and to organic superconductors. Inspired by the results for "dusty plasma" and Abrikosov lattice melting, I will try to construct general theory of melting using the idea that it becomes second order in D=4.

Keywords: high Tc superconductor, vortex, melting, p,d-wave, nonperturbative phenomena.

三、研究成果報告

Structural phase transition in Vortex lattice of high Tc superconductors. Second peak effect.

In series of works my high Tc group developed a one component Ginzburg - Landau effective theory of d - wave superconductors [8], and applied it to analyse recent neutron scattering experiments [9]. This is first application of the simplified one component model to describe structural transitions in vortex lattices and time dependent nonlinear VA characteristics of YBCO. Next we worked out a theory of structural phase transitions and the second peak effect in good agreement with experiment in Argonne (done after the theory), see [16]. The theory was well received.

First principles theory of fluctuations in superconductors

To approach the region below the mean field transition line Thouless proposed a perturbative approach around homogeneous (liquid) state was in which all the "bubble" diagrams are resummed. The series provide accurate results at high temperatures, but for low temperatures become inapplicable. Alternative, more direct approach to low temperature fluctuations physics is to start from the Abrokosov solution at zero temperature and then take into account perturbatively deviations from this inhomogeneous solution.

I showed in [15,20] that all the IR divergencies in free energy or other quantities invariant under translations cancel to the two loop order. I calculate magnetization and specific heat to this order, interpolate with existing high temperature expansion and compare with Monte Carlo (MC) simulation and experiments.

Then we with D.P. Li considered higher Landau levels in [17]. Structure function and disorder effects were tackled in [18]. The melting problem and fluctuations of the magnetic field was finally solved in [26,27, review 1].

Flux phases and skyrmions in p - wave superconductors

It is well known that some heavy fermion compounds like UPt3 and recently discovered Ru based superconductors are p- wave superconductors. Magnetic properties of some of these superconductors might be quite unusual: they behave ferromagnetically. We with A. Knigavko found that at zero field under some circumstances spontaneous vortex phase is formed [11]. The mixed phase in type II superconductors with equal spin p - wave pairing is considered using Ginzburg - Landau approach. Due to direct spin coupling of the condensate to magnetic field the mixed state acquires ferromagnetic properties. For sufficiently large Zeeman coupling spontaneous vortex phase appears at H=0 and exists for arbitrarily large magnetic field. Meissner phase therefore completely disappears. Vortices become thinner when H grows. There exists a value of Zeeman coupling above which in the presence of external magnetic field mixed phase might occur even for temperatures above T_{c}. The structure of the vortex core is markedly different from the usual one.

Incidentally we found a very interesting new phenomenon in UPt3, a heavy fermion superconductor, long suspected to be a p wave superconductor. At low inductions it has skyrmions instead of usual Abrikosov vortices [12,14]. The magnetization curve acquires a characteristic parabolic shape.

Vortex dynamics in the mixed state

In [4] the dynamics of Kosterlitz-Thouless pairs in YBCO thin films has been considered for the first time. KT pairs get pinned and survive even upon cooling to liquid He temperatures. I with collaborators from NTHU developed a renormalization group method to study these dynamical phenomena. This is now beeing measured by Clarke's group in Berkeley using SQUID microscope.

With A. Kasatkin we found resonance in the microwave frequencies response of superconductors in the superclean limit. In this limit (first achieved recently by the Princeton group) the Magnus forse is more important then usual Bardeen - Stephen friction. The resonances are due to excitation of the rotation of vortex segments around pinning centers [19].

五、參考文獻

看附件 **(publication list since 1996)**

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B. Rosenstein

Report on my trip to Europe (UK, Israel) during summer vacation

1. The 11th International Conferences on Recent Progress in Many-Body Theories

July 9 to July 13, 2001. This is a major International conference in the field previously held at Seattle (99), Sidney (96). All major applications of field theory in physics were represented. A copy of the Conference topics and my poster are attached.

2. Collaboration with superconductivity group in Bar Ilan University, Ramat Gan (Israel).

July 20 to August 25

I collaborate effectively with Prof. B. Shapiro and experimental high Tc group of Bar Ilan University led by Prof. Y. Yeshurun on magnetization in YBCO. Last summer my short visit (paid largely by myself) resulted in the following work: Rosenstein, Shapiro, Prozorov, Yeshurun, Phys. Rev. B63 , 134501 (2001). We continued to work with B. Ya. Shapiro and almost finished a work "Nonstandard vortices in p-wave superconductors" to be submitted to Phys. Rev. Let.. During the visit was invited to the Taiwanese rep. In Tel Aviv. Participated with him in a meeting in Israeli Academy of Sciences.

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3. Visit to Hebrew University. Superconductivity group of Prof. E. Sonin

July 15 – 19.

Initiated cooperstion with Prof. Sonin. Hope he and Prof. Ya. Rosenfeld will come this year to Taiwan.