QUANTUM CREEP IN HTSC AT LOW TEMPERATURE AND HIGH PURITY LIMIT

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The rate of tunneling of the flux line in lauered superconductor, under the Influence of the external current, in $H\|ab$ geometry, is calculated on the basis of "vortice-diolocation" analogy, in the high purity limit and $T\to 0$. It is compared with the results recieved with the dissipation taken into account, in the framework of Caldeira-Legett theory.

The possibility of quantum creep in superconductors was mentioned first time in the work of A.V. Mitin [1]. Later quantum creep in high-T_c anisotropic superconductors was considered in the framework of collective creep model [2].

It is common wisdom that for superconductive ceramic materials strong dissipation should be taken into account, for instance, on the basis of Caldeira-Legett approach [3]. Calculations of fluxline's rate of tunneling through a potential barrier with negligence of dissipation [4] were not considered realistic.

But in the article of A.I. Larkin et al. [5] authors drew attention to the fact that at low temperatures for very clean materials underdamped regime takes place. In that case fluxllne's motion is similar to the motion of vortices in superfluid helium. The criterion dividing the underdamped case (week dissipation) from over-damped one (strong dissipation) is determined by [6]:

$$l \gg \xi \frac{E_F}{\Delta} \tag{1}$$

where l is the mean free pass, ξ - the coherent length of superconductor, E_F - Fermi energy, Δ - the superconductor gap. For usual superconductors E_F/Δ is about 10^3 and for HTSC it is ~10. Taking into account very short coherent length of HTSC one comes to the conclusion that for pure HTSC at low temperatures nondissipative regime takes place. So, it makes sense to compare at that limit the results of [4] with other publications.

We are considering a fluxline in the washboard potential formed by layered structure of high-T_c superconductor, with the external current flowing in ab plane in parallel to x-axis. Washboard potential W and the hamiltonian H are given by:

$$W = U_0 \sin\frac{2\pi}{b} y - \frac{\Phi_0}{c} J \cdot y \tag{2}$$

$$H = \iint dt dx \left[\left(\frac{\partial y(x,t)}{\partial t} \right)^2 + W(y(x,t)) \right] \tag{3}$$

The dissipation is neglected here. The question is what is the tunnelling rate per unit length. This problem was considered in [7] for description of creep of a dislocation line under external stress at low temperatures. It is necessary to find the function $y(x)$ which minimises the action. The authors of [7] (further PP) received exact solution due to the fact that in configurational space the narrow potential valley connecting starting and final configurations exists. The result for tunnelling rate reformulated for a fluxline is:

$$\Gamma \sim \exp\left(-\frac{S_E^{eff}}{h} \right)$$

$$\Gamma = \begin{cases} \exp\left[-\frac{16}{3} \left(\frac{\mu}{2l_1} \right)^{1/2} \frac{V_1^{3/2}}{hF} \right] & \text{for } F \ll F_p \\ \exp\left[-10 \left(F_p - F \right) \frac{(\varepsilon\mu)^{1/2}}{h\beta} \right] & \text{for } F \le F_p \end{cases} \tag{4}$$

where l_i - the length of the kink, V_i - the energy of the kink, F_p - Peierls stress, μ - the mass of a segment of the unit length,

$$\mu = \frac{12\pi}{8} mn\xi^2 \left(\frac{\Delta}{E_F} \right)^2, \quad F = \frac{\Phi_0}{c} J, \quad F_p = \frac{2\pi}{b} U_0,$$
$$l_1 = b\left(\frac{\varepsilon}{2U_0} \right)^{1/2}, \quad V_1 \approx \frac{2b}{\pi} \left(2U_0\varepsilon \right)^{1/2} \tag{5}$$

To take into account the dissipation one has to change the kinetic term of the action to the non local expression [8]:

$$\frac{S_E^{diss}}{h} = \iint dtdt' \int dx \frac{1}{2} m_{eff} \frac{\partial y(t)}{\partial t} \frac{\partial y(t')}{\partial t'} \quad (6)$$

The authors of [8] made the estimation of S_E^{eff} based on heuristic arguments: $S_E^{eff} \sim t_c U_0$. Here U_0 is pinning energy (in our case the amplitude of sinusoidal potential), t_c is received from equating kinetic term to elastic one and, finally,

$$\frac{S_E^{eff}}{h} = \frac{h}{1^2} \frac{\xi}{\rho_n} \left(\frac{j_o}{j_c}\right)^{1/2} \quad (7)$$

The authors of [9] considered the collective creep in anisotropic superconductor with randomly distributed pinning centers. Periodicity of flusline's potential were not Included In the model, the pinning force was uniformly distributed with correlation function:

$$<f_i(r) f_j(r')>=f^2 n\delta(r-r')\delta_{ij}$$

where n is the concentration of pinning centers.

The authors estimated the effective action for zero dissipation as

$$\frac{S_E^{eff}}{h} \sim t_c U_c \sim \alpha \cdot \xi^2 \sqrt{E_0 M} \quad (8)$$

where M is the mass of a vortex segment of unit length, $\varepsilon_0 = (\Phi_0/4\pi\lambda)^2 \ln(\lambda/\xi)$ and α - anisotropic parameter.

The absence of dependence on j seems to be the consequence of unrealistic uniform distribution of the pinning force.

In the paper of R.Griessen, J.G. Lannink and H.G.Schack [10] zero and strong dissipation limits were considered, and the estimations for tunnelling rate were done. A fluxline was considered as a stiff rode length 1, so elasticity was neglected. The fluxline was in periodic potential which was tilted by the external current. The effective action for strong dissipation case calculated in the framework of Caldeira-Legett theory was given by $S_E^{eff} = A\eta(x_b - x_a)^2/h$, where $\eta = (\Phi_0^2 1/2\pi\xi^2\rho_n)$ - Stephan-Bardeen damping coefficient for stationary flow (which is not actually the case), $A \sim 1$, $x_b - x_a = 3 \cdot 2^{1/2} x_{hop} (1 - j/j_c)^{1/2}/\pi$; x_a and x_b are starting and final final coordinates of tunnelling segment respectively, x_{hop} -the distance between two adjacent minimums of periodic potential. So

$$S_E^{eff} = \eta x_{hop} (j_c - j)/j_c$$

It has j dependence similar to PP result for strong external force which is due to WKB like expression for tunnelling particle In both oases. For strong external force (current) the critical nucleation length [7]:

$$L_c = [\varepsilon/U''(0)]^{1/2} \ln[bU''(0)/2F] \quad (9)$$

is short, elasticity plays minor role and a fluxline segment tunnelling through a potential barrier may be considered as a point-like object. In PP theory, at weak external stress the critical length diverges to infinity being proportional to $\ln(1/F)$, and exponential factor of S_E^{eff} is proportional to $1/F$, whereas in the work of Griessen et al. the $S_E \sim A\eta x_{hop}$ which is just a Caldeira-Legett expression for tunnelling exponent of a point-like object.

There are essential differences between [4] and works [8,9,10] in description of tunnelling process in HTSC in the pure limit at low temperatures. Quantum creep in pure HTSC connected with tunnelling of fluxline through regular potential barriers of a periodic potential formed by layered structure of HTSC presented in works [8,9,10] does not have divergence in small current limit at low T and high purity whether the calculations are done for strong or zero dissipation cases. On the contrary, in t4] it was described on the basis of PP theory, as a process similar to nuclear on in condensed matter physics. Due to quantum fluctuations the segment of length not less than critical tunnels through a barrier and the whole fluxline crawls over the potential barrier thereafter. It is analogous to the droplet model in statistical mechanics [11], decay of false vacuum In quantum field theory [12] etc.

Experimental measurements at that limit could be helpful In determination of adequacy of the model [4].

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YTİK-LƏRDƏ, AŞAĞI TEMPERATURLARDA İFRAT SIRF HÜDUDDA, SELİN KVANT KRİPİ

Selin kvant kripini tə'yin edən, "dislokasiya-burulğan" analogiyası əsasında hesablanmış, $H\|ab$ həndəsəsi daxilində laylı yüksək temperaturlu ifratkeçiricilərdə (YTİK) xarici cərəyanın tə'siri altında maqnit burulğanının tunelləşmə ehtimalı aşağı temperaturlarda sırf ifratkeçirici hüdudunda Kaldeyr-Leqett nəzəriyyəsi çərçivəsi daxilində dissipasiyanın nəzərə alınması şərtilə alınmış nəticələrlə müqayisə edilir.

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КВАНТОВЫЙ КРИП ПОТОКА В ВТСП ПРИ НИЗКИХ ТЕМПЕРАТУРАХ В СВЕРХЧИСТОМ ПРЕДЕЛЕ

Вероятность туннелирования магнитного вихря под воздействием внешнего тока в слоистых высокотемпературных сверхпроводниках (ВТСП) в геометрии $H\|ab$, определяющая квантовый крип потока, вычисленная на основе аналогии "дислокация-вихрь", сравнивается в пределе чистого сверхпроводника при низких температурах с результатами, полученными с учетом диссипации в рамках теории Калдейра-Легетта.

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