Vortex viscosity in moderately clean layered superconductors

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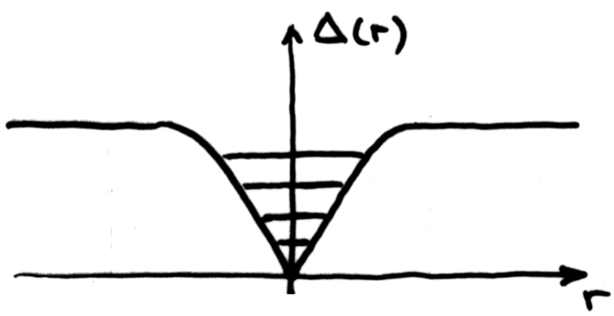
Question:

How discreteness of energy levels in the core of a 2D vortex affects the classical result on the vortex viscosity (Bardeen-Stephen '65)

[Answer: it does not !]



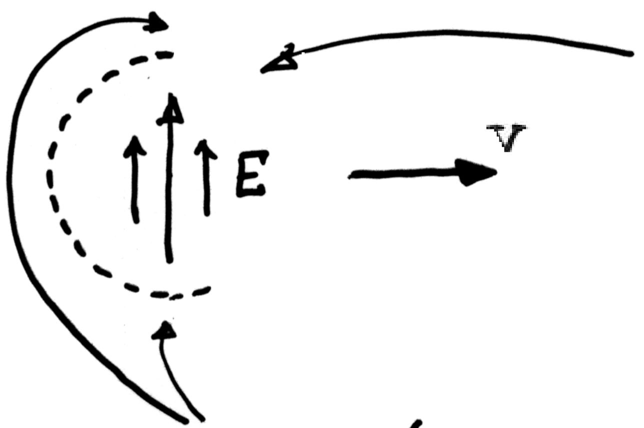
Motivation:

1. (Larkin, Ovchinnikov Kulakov '98-99)
At low impurity concentration, the discrete levels in the vortex core are highly correlated (two-comb structure) not completely random

2. (Wilkinson '98)
For time-dependent Hamiltonians from the Wigner-Dyson random-matrix ensembles the energy pumping rate ($\rightarrow$ viscosity) has different mechanisms and different asymptotics at high and low velocities [scaled: (average level velocity)*/interlevel spacing^2]
At low velocities, the viscosity depends the level repulsion β

$$\eta \sim v^{(\beta-2)/2}$$

Bardeen - Stephen (classical) theory of vortex viscosity



vortex = normal region of size ξ inside a superconductor

$\varphi \quad v/\xi \quad \Rightarrow$ transverse electric field

$$E \quad \varphi/\xi \quad v/\xi^2$$

$$\Downarrow$$

energy dissipation $\quad \sigma_n E^2 \xi^2$

ξ^2 ← area of the core

$$\Downarrow$$

viscosity $- \dfrac{\text{dissipation}}{v^2} \quad \dfrac{\sigma_n}{\xi^2} \quad \dfrac{\tau \varepsilon_F}{\xi^2}$

(per vortex)

(Quasiclassical calculations

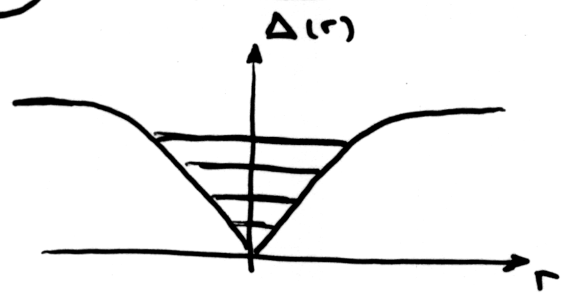
Gorkov Kopnin 73

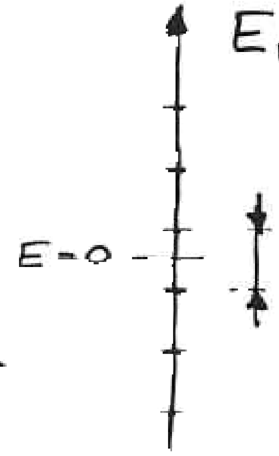
Larkin Ovchinnikov 76

)

Discrete levels in the vortex core

1. Pure vortex (no impurities)





$E_n \quad \omega_0 (n + 1/2)$

$\omega_0 \sim \dfrac{\Delta^2}{\varepsilon_F} \ll \Delta$

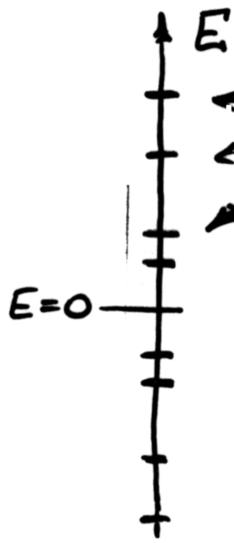
quasiclassical parameter

$k_F \xi \quad \varepsilon_F/\Delta \gg 1$

(Caroli de Gennes Matricon '64)

2. Dirty vortex (strong disorder

$\Delta \tau \ll 1$)



randomly shifted levels

Class C random matrix ensemble

$$dP\{\omega_n\} \propto \prod |\omega_i^2 - \omega_j^2|^{2}\, \omega_i^2\, d\omega_i$$

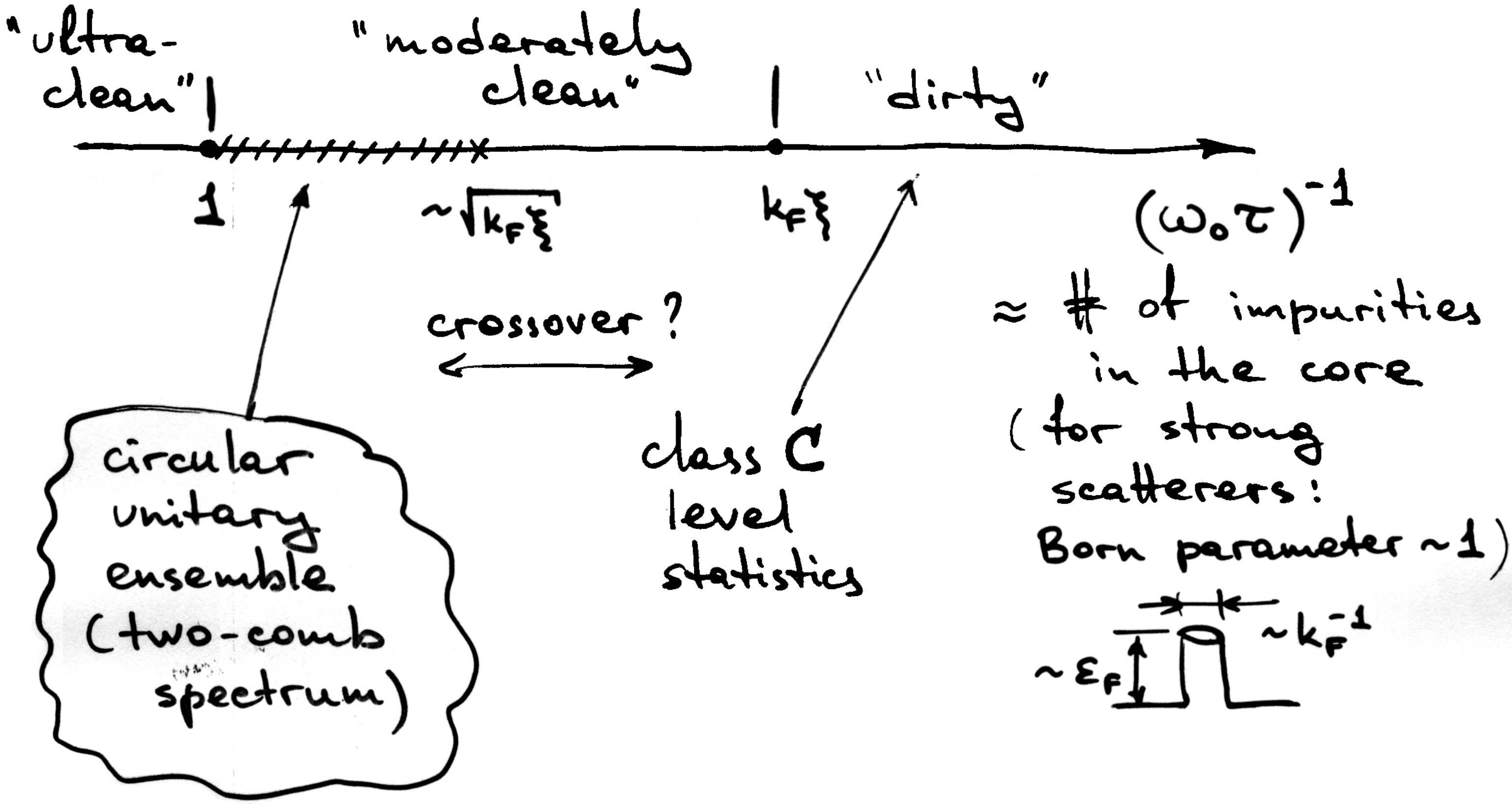
β level repulsion parameter

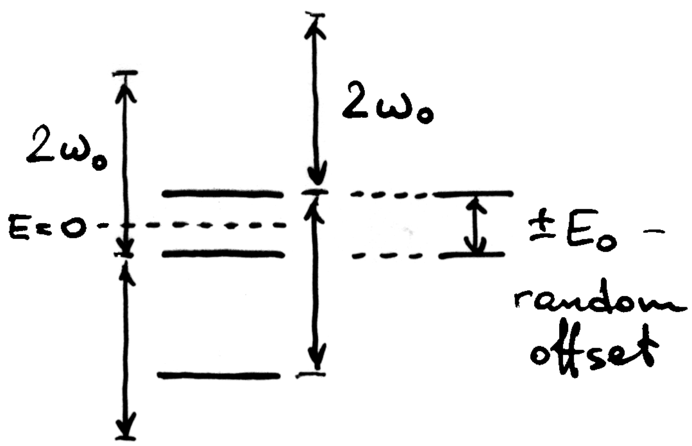
Skvortsov Kravtsov Feigelman '98

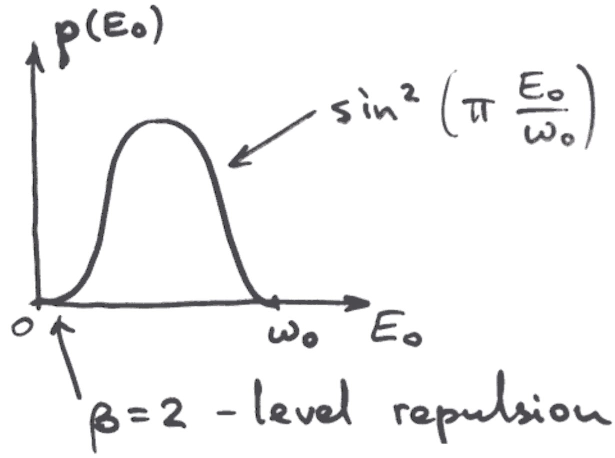
Bundschuh Cassanello, Serban Zirnbauer 98)

In-between: "moderately clean" regime

(Kulakov, Larkin '99)







$E_0 = \frac{\varphi}{\pi}\omega_0$

$e^{\pm i\varphi}$ - eigenvalues of a random SU(2) matrix