An *ab initio* study of the Little-Parks effect

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• Cylindrical superconductor held at transition temperature and threading flux is increased

Little & Parks, PRL 1962
Little-Parks in a large diameter cylinder

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- Reduce cylinder diameter to superconducting correlation length [Liu et al., Science 2001; Wang et al., PRL 2005]
How to calculate the current

- General expression for the current [Meir & Wingreen, PRL 1992]

\[ J = \frac{i\epsilon}{2\hbar} \int d\epsilon \left[ \text{Tr} \left\{ (f_L(\epsilon)\Gamma^L - f_R(\epsilon)\Gamma^R) (G_{e\sigma}^r - G_{e\sigma}^a) \right\} + \text{Tr} \left\{ (\Gamma^L - \Gamma^R)G_{e\sigma}^< \right\} \right] \]

- Use the disordered negative-\(U\) Hubbard model to describe the superconductor

- Calculate the thermal average with Monte Carlo method
Verification

- Resistivity at the Kosterlitz-Thouless transition
- Nonlinear IV characteristics
- Length dependence of conductivity
- BTK transmission coefficient
- Three-body interactions
- Josephson junction
- Little-Parks effect in large diameter cylinder

Ambegaokar et al., PRB 1980
Verification

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Little-Parks in a small diameter cylinder

Theory:

Experiment:
Little-Parks in a small diameter cylinder

Theory:

\[
\frac{R}{R_0} \quad r = 0 \\
\frac{R}{R_0} \quad r = \alpha
\]

Experiment:

\[
R(\Omega) \quad T(K) \\
\Phi/\Phi_0
\]
Little-Parks in a small diameter cylinder

Experiment:

Theory:
Little-Parks in a small diameter cylinder

Experiment:

Theory:
Evidence of phase reconstruction

- **Experiment:**

- **Theory:**
Completely superconducting

\[ \frac{V - \mu_R}{\mu_L - \mu_R} \]

Superconducting current
Normal current

\[ \langle \cos(\theta_1 - \theta_2) \rangle \]
Three superconducting regions

Superconducting current

Normal current

\[ \langle \cos(\theta_1 - \theta_2) \rangle \]
Half flux quantum normal state

Superconducting current

Normal current

$$\langle \cos(\theta_1 - \theta_2) \rangle$$
Summary & future prospects

- Understood how normal regions emerge in a cylindrical superconductor.
- Formalism can address other long-standing experimental questions:
  - **Giant magnetoresistance**
    - [Sambandamurthy 04]
  - **Non-monotonic $RT$ curves**
    - [Jaeger 89, Baturina 07]