Decreasing excitation gap in Andreev billiards by disorder scattering

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Andreev billiards

Ballistic quantum billiard (N) in contact with a superconductor (S)

Andreev reflection \[1\] Normal reflection

Electron reflected back as hole

Periodic electron-hole orbits inbetween two Andreev reflections

Proper delay times

Eigenenergies of closed Andreev billiards \[4\]

$$\text{det}[1 + S(E)S^\dagger(-E)] = 0 \iff E = \frac{\hbar \pi}{2 \tau_{WS}}$$

$$\tau_{WS}:$$ Eigenvalues of the Wigner-Smith delay time matrix $Q = -i\hbar S^\dagger \partial_x S$ \[5\].

Lowest eigenenergy $E_1$ (gap size) determined by largest $E_{1,\tau_{WS}} \approx \frac{\hbar \pi}{2}$

WS delay time value $\tau_{WS}$.

Mean delay time $\langle \tau \rangle$ unafected by disorder as predicted by \[6\].

Average dwell time $\langle \tau_0 \rangle$, \[6\].

Largest WS delay time predicts decreasing excitation gap quantitatively

Correlation between delay time and gap size

Increasing $V_F$

Correlation between maximal WS delay time value $\tau_{WS}$ and gap size

$E_1 = \frac{\hbar \pi}{2 \tau_{WS}}$

Gap size reduced by disorder

Mean delay time (dwell time) unrelated to gap

Correlation between maximum Wigner-Smith delay time and gap size

Strong disorder breaks correlation between maximum Wigner-Smith delay time and gap size

Wavefunctions

Clean system

Electron-hole wave functions lose mirror symmetry for increasing disorder

Disordered system

Excitation gap

Result for SN junctions \[3\]: Disorder shifts lowest eigenenergy $E_1$ away from Fermi energy

Correlated on-site disorder potential in N-region, characterized by

$$\langle V' \rangle = 0 \quad \sqrt{\langle V'^2 \rangle} = V_0 \quad l_{corr.} = 0.2 \lambda_F$$

No gap at $V_f = 0$.

Gap increases with increasing disorder!

Gap decreases with increasing disorder

Largest gap at $V_f = 0$.

RMT estimate for $E_1$

Conclusions

• Gap size reduced by disorder
• Mean delay time (dwell time) unrelated to gap
• Correlation between maximum Wigner-Smith delay time and gap size
• Strong disorder breaks correlation between maximum Wigner-Smith delay time and gap size

Future Projects

• Effects of dissipation and decoherence
• Time-dependent Andreev scattering
• Transport through open Andreev billiards

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References


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