Spontaneous trapping of magnetic quanta in an annular Josephson junction

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Abstract

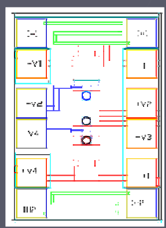
The aim of the project is to investigate spontaneous symmetry breaking in non-adiabatic phase transitions (Zürek-Kibble process). A long and narrow annular Josephson tunnel junction sandwiched between two superconducting rings is subjected to repeated thermal quenches through the normal-superconducting transition temperature. The quench rate is varied over 4 orders of magnitude. The spontaneous production of topological defects, fluxons, is studied by detection of zero-field steps. An allometric scaling behavior is found with a critical exponent close to -0.5, which does not agree with earlier experiments and theoretical predictions of -0.25. The main experimental challenges of the project are to create well-defined nearly identical quenches, automating the data analysis and suppressing external magnetic fields and noise by passive magnetic shielding and compensation. Further experiments on the effect of magnetic fields are in progress.

Theory

- Basic idea, Kibble(1980)[1]
  - Information has a maximum velocity of transmission
  - Phase transitions involve transmitting information
- Zurek(1996)[2] proposed condensed matter systems for testing the theory
  - Superconductors
  - Superfluids
- E. Kavoussanaki *et al.*(2000)[3] proposed testing in annular Josephson Tunneling Junctions – AJTJs

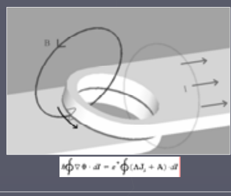
For $\xi >> C$, the trapping rate is given by the allometric formula

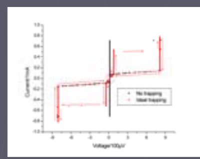
$$f_1 \sim C/\xi \sim \tau_Q^{-1/4}$$



Topological defects

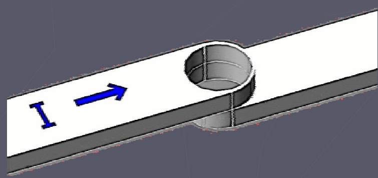
In the AJTJ the topological defects are fluxons – magnetic flux quantum loops threading the oxide layer of the junction. The presence of a fluxon is detected through a change in the I-V curve of the junction as seen in the figure. This feature is called a Zero-Field Step, ZFS.



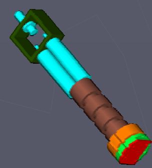


The setup

Sample geometry



Sample holder



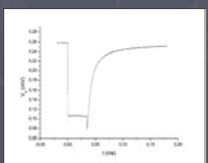
Thermal cycling

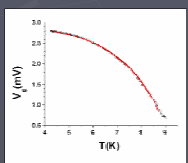
Challenges

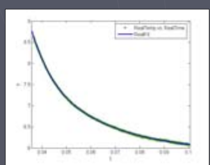
- Measuring cooling rate at $T=T_C$
- Reproducible cycles within several decades of cooling rates
- No electrical connections during transition time

Quench time:

$$\tau_Q = -T_C\,(dT/dt|_{T=T_C})^{-1}$$

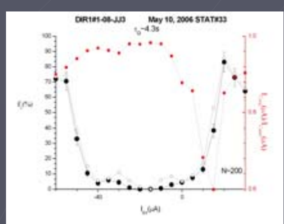


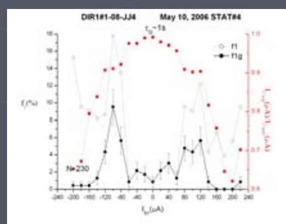




Magnetic fields

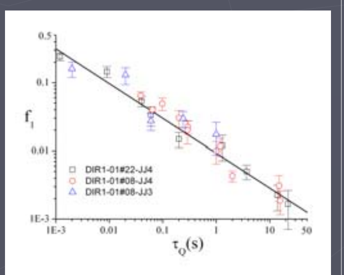
The effect of an applied orthogonal magnetic field on trapping rate is studied. This also illustrates the effect of the magnetic field on the surrounding film – possibly by trapping of Abrikosov vortices. A minimum is expected at zero net field.





Main Result

- Allometric scaling found
  Probability vs Quench time
- Critical exponent ~ -0.50
- Reproduced with 3 samples
- Variation of cooling rate around 10% across 10^4 cycles
- Reproduced over 4 decades of cooling rates



Conclusion

The experimental results produced show a clear allometric scaling behavior of defect formation on quench time. This is a validation of the basic idea of Kibble and Zürek. The exact critical exponent is a result of the particulars of the system, and a new theoretical explanation for this has been proposed[4].

New experiments on the dependence of induced trapping on an applied magnetic field is in progress.

References

[1]T. W. B. Kibble, Phys. Rep. **67**, 183 (1980).
[2]W. H. Zurek, Phys. Rep. **276**, 177 (1996).
[3]E. Kavoussanaki, R. Monaco, and R. J. Rivers, Phys. Rev. Lett. **85**, 3452 (2000)
[4]R. Monaco, J. Mygind, M. Aaroe, R. J. Rivers, and V. P. Koshelets, Phys. Rev. Lett. 96, 180604 (2006)