Langevin Molecular Dynamics of Driven Magnetic Flux Lines

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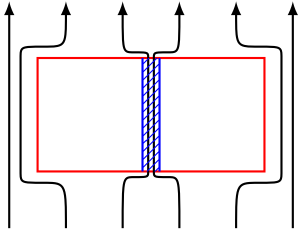
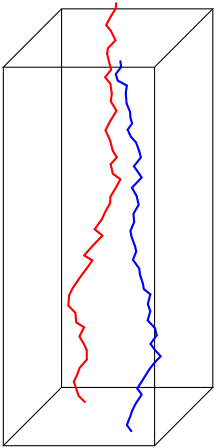
Motivation

- Type II superconductors exhibit a second order phase transition from superconducting to normal state
- Magnetic flux penetrates above critical field H_{c1} through vortex lines - each one carries a flux quantum



- Vortex lines movement generates dissipation
- Pinning by (artificially introduced) defect sites - optimization
- Complex and rich system that is accessible in experiments
- High T_C SC - interesting for technology and applications

Elastic Line Model



After coarse graining: Vortex lines are interacting elastic lines†

$$F_{el} = \sum_{j=1}^{N} \int_0^L dz \left[\frac{\epsilon_1}{2} \left| \frac{d\vec{r}}{dz} \right|^2 + \frac{1}{2} \sum_{i \neq j}^{N} V_I(|\vec{r}_{ij}|) + V_D(\vec{r}_j) \right]$$

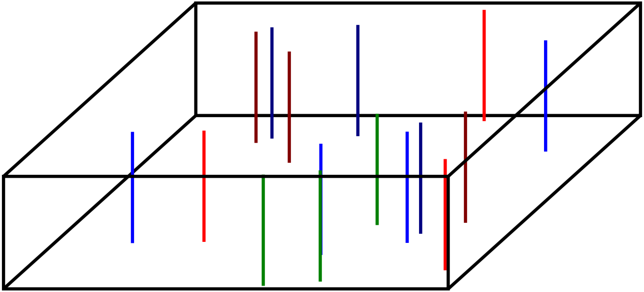
- Elastic energy ϵ_1 (stiffness)
- Line interaction energy $V_I(|\vec{r}_{ij}|) \propto K_0(|\vec{r}_{ij}|)$
- Defects potential $V_D(\vec{r})$ due to pin sites
- This work: only random point defects

Discretize lines into connected particles → simulations

†D.R. Nelson and VM Vinokur PRB 48 13060 (1993), T. Klongcheongsan, TJ Bullard, and UC Täuber, Supercond Sci Tech 23 025023 (2010)

Visualization

LMD simulation of interacting vortex lines in clean system
$\rightarrow$ form hexagonal lattice



$t = 0$

Methods

Monte Carlo

Find steady state by performing a biased random walk on the energy landscape

- Problem: external drive enters energy - not well defined for relaxation into non-equilibrium steady-state

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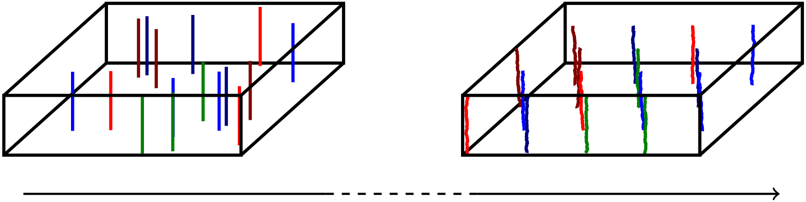
Langevin Molecular Dynamics Algorithm

Solve the system of coupled Langevin equations

$$\ddot{\vec{r}}_i = -\zeta \dot{\vec{r}}_i + \vec{F}(\{\vec{r}_j\}) + \sqrt{2\zeta k_B T}\vec{R}(t)$$

- Additional random force term $\vec{\eta}$ describing fast degrees of freedom - temperature bath
- Gaussian white noise $\langle R_i(t) R_j(t') \rangle = \delta_{ij}\delta(t - t')$
- Problem: also not well defined for non-equilibrium (driven) systems

Time regimes



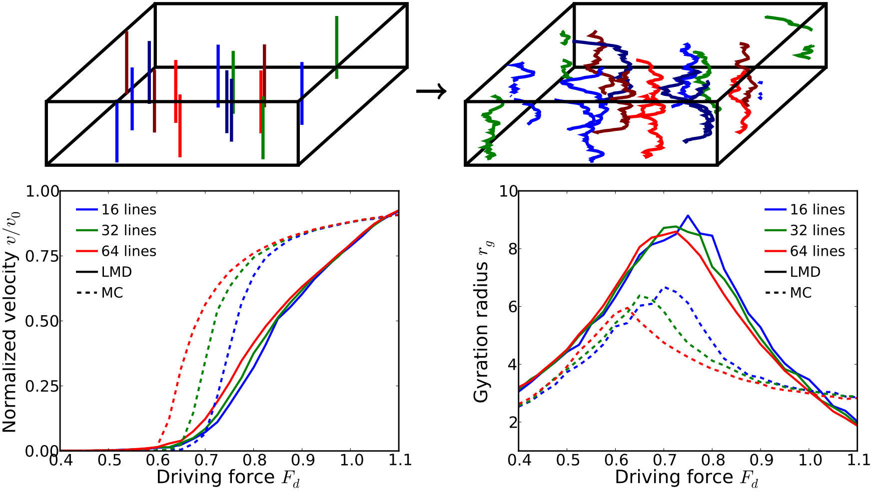
Transient regime

- Dependent on inital conditions
- Dynamical scaling - aging
- Time translation invariance broken
- Need two-time quantities to characterize

Steady state

- Time translation invariance recovered
- No dependence on initial conditions
- All quantities stationary in thermodynamic limit

Driven system results

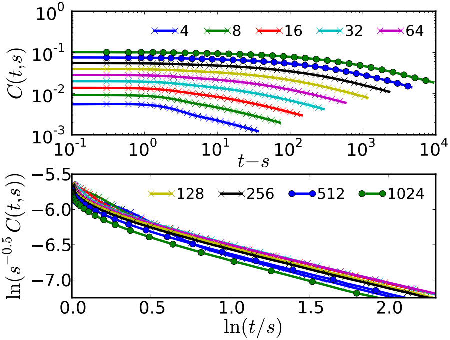


- 16, 32 or 64 initially straight lines placed at random positions
- 34200 randomly distributed point defects
- Driven system, allowed to relax into steady state
- Agreement between MC and LMD good

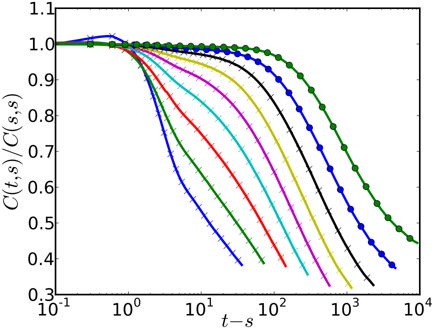
Two-time height-height autocorrelation

LMD yields similar results as previously performed MC simulations†

No defect sites



Disordered system



- Dynamical scaling - aging exponent ≈ 0.5
- Disorder leads to glass-like relaxation

†M. Pleimling and U.C. Täuber, *arXiv*:1106.1130 (2011)

Summary

Conclusion

- Complex out-of-equilibrium system
- Important to understand vortex dynamics to optimize technological applications
- Both methods yield comparable results - complementary to each other
- LMD is much more efficient

Outlook

- Aging regime – universality/scaling
- Correlated defects
- Thin films
- Relaxation of driven systems

Thank you for your attention!

References

- D.R. Nelson and VM Vinokur *PRB* 48 13060 (1993)
- T. Klongcheongsan, TJ Bullard, and UC Täuber, *Supercond Sci Tech* 23 025023 (2010)
- M. Pleimling and U.C. Täuber, *arXiv*:1106.1130 (2011)

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