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Regimes of strong vortex pinning in high-temperature superconductors

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To make superconductors technologically relevant, it is crucial to immobilize magnetic flux lines (vortices) threading the material. Capturing the pinning mechanism starting from microscopic interactions of vortices with defects poses a very difficult problem. The theory of strong vortex pinning provides a starting point to address this problem. We revisit the different regimes of strong-pinning theory and investigate them using large-scale numerical solutions of the time-dependent Ginzburg-Landau equations [1-3]. We explore the magnetic-field dependences of the critical current, jc(B), for superconductors containing spherical inclusions with different sizes and densities. Within a wide range of parameters, the vortex configuration is disordered and features a power-law decay of $jc(B) \sim B_{-\alpha}$, where the power index α decreases with the particle density. We find a first-order transition of the pinning ground state towards double-occupancy of defects leading to a non-monotonic pin-breaking force and peak effect. Our results provide a framework for interpretation of pinning properties of real materials.

[1] R. Willa et al., Physical Review B **93** 064515 (2016)
[2] R. Willa et al., Superconductor Science and Technology **31** 014001 (2017)
[3] R. Willa et al., Physical Review B **98** 054517 (2018)