University of Michigan Experiment Explores Avalanche Behavior in Vortices

Physicists at the University of Michigan have produced direct, experimental evidence showing that magnetic field lines called vortices that pass through a superconductor form avalanches similar to grains of sand in a collapsing sandpile. Although the existence of avalanche behavior in vortices has been reported before, these are the first real-time 'pictures' documenting the sizes, lifetimes, and arrival times of vortex avalanches as they spill out of a superconducting sample.

The avalanche phenomenon occurs in diverse and seemingly unrelated systems, such as sandpiles, magnetic fields, earthquakes, water droplets, and electronic circuits. But according to Stuart B. Field, a physics professor at the university who led the experiment, it is not the differences in materials that are fundamental to the question, but the nature of the forces acting on these complex systems.

"In every case, these systems maintain a balance between an external driving force and some internal pinning or friction mechanism," he said. "The external force drives the system just to the threshold of instability. The internal force holds the materials in place. When the system becomes unstable, a sudden burst of energy is released in the form of an avalanche--of sand grains, vortices, water droplets, or whatever--to bring it back into balance."

To test this concept, Field immersed a hollow tube made of a niobium/titanium superconductor in a liquid helium bath. He then introduced an external driving force by slowly ramping up the magnetic field outside the sample, thus driving the magnetic flux into the tube's outer wall in the form of vortices. Passing through the tube, the vortices became trapped in defects within the superconducting material, which pin the vortices in place.

When the vortices emerged through the tube's interior wall, they did so not at a smooth, steady rate, but in surges or avalanches that were detected as a voltage pulse on an electronic coil inside. From the shape of the pulses, one can infer the number of vortices in each avalanche. The observed avalanches varied in size from as few as 50 vortices to nearly 5,000 vortices.

Still, many questions remain unanswered, such as why avalanche activity changes at different magnetic fields and temperatures. "With low magnetic fields, there's no activity," said Jeff Witt, a graduate student who worked on the experiment with Field. "As you increase the field, activity begins, but then starts to decline again above a certain field intensity. We see a similar pattern with temperature variation. There's a great deal we simply don't yet understand."

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