

New model describes avalanche behavior of superfluid helium

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By utilizing ideas developed in disparate fields, from earthquake dynamics to random-field magnets, researchers at the University of Illinois have constructed a model that describes the avalanche-like, phase-slip cascades in the superflow of helium.

Just as superconductors have no electrical resistance, superfluids have no viscosity, and can flow freely. Like superconductors, which can be used to measure extremely tiny magnetic fields, superfluids could create a new class of ultra-sensitive rotation sensors for use in precision guidance systems and other applications.

But, before new sensors can be built, scientists and engineers must first acquire a better understanding of the odd quirks of superfluids arising in these devices.

In the April 23 issue of *Physical Review Letters*, U. of I. physicist Paul Goldbart, graduate student David Pekker and postdoctoral research associate Roman Barankov describe a model they developed to explain some of those quirks, which were found in recent experiments conducted by researchers at the University of California at Berkeley.

In the Berkeley experiments, physicist Richard Packard and his students Yuki Sato and Emile Hoskinson explored the behavior of superfluid helium when forced to flow from one reservoir to another through an array of several thousand nano-apertures. Their intent was to amplify the feeble whistling sound of phase-slips associated with superfluid helium

passing through a single nano-aperture by collecting the sound produced by all of the apertures acting in concert.

At low temperatures, this amplification turned out, however, to be surprisingly weak, because of an unanticipated loss of synchronicity among the apertures.

"Our model reproduces the key physical features of the Berkeley group's experiments, including a high-temperature synchronous regime, a low-temperature asynchronous regime, and a transition between the two," said Goldbart, who also is a researcher at the university's Frederick Seitz Materials Research Laboratory.

The theoretical model developed by Pekker, Barankov and Goldbart balances a competition between interaction and disorder – two behaviors more commonly associated with magnetic materials and sliding tectonic plates.

The main components of the researchers' model are nano-apertures possessing different temperature-dependent critical flow velocities (the disorder), and inter-aperture coupling mediated by superflow in the reservoirs (the interactions).

For helium, the superfluid state begins at a temperature of 2.18 kelvins. Very close to that temperature, inter-pore coupling tends to cause neighbors of a nano-aperture that already has phase-slipped also to slip. This process may cascade, creating an avalanche of synchronously slipping phases that produces a loud whistle.

However, at roughly one-tenth of a kelvin colder, the differences between the nano-apertures dominate, and the phase-slips in the nano-apertures are asynchronous, yielding a non-avalanching regime. The loss of synchronized behavior weakens the whistle.

"In our model, competition between disorder in critical flow velocities and effective inter-aperture coupling leads to the emergence of rich collective dynamics, including a transition between avalanching and non-avalanching regimes of phase-slips," Goldbart said. "A key parameter is temperature. Small changes in temperature can lead to large changes in the number of phase-slipping nano-apertures involved in an avalanche."

Source: University of Illinois at Urbana-Champaign

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