Nanomechanical device bridges classic and quantum physics

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Nanotechnology leapt into the realm of quantum mechanics this past winter when an antenna-like sliver of silicon one-tenth the width of a human hair oscillated in a lab in a Boston University basement. With two sets of protrusions, much like the teeth from a two-sided comb or the paddles from a rowing shell, the antenna not only exhibits the first quantum nanomechanical motion but is also the world's fastest moving nanostructure.

A team of Boston University physicists led by Assistant Professor Pritiraj Mohanty developed the nanomechanical oscillator. Operating at gigahertz speeds, the technology could help further miniaturize wireless communication devices like cell phones, which exchange information at gigahertz frequencies. But, more important to the researchers, the oscillator lies at the cusp of classic physics, what people experience everyday, and quantum physics, the behavior of the molecular world. Comprised of 50 billion atoms, the antenna built by Mohanty's team is so far the largest structure to display quantum mechanical movements.

"It's a truly macroscopic quantum system," says Alexei Gaidarzhy, the paper's lead author and a graduate student in the BU College of Engineering's Department of Aerospace and Mechanical Engineering. The device is also the fastest of its kind, oscillating at 1.49 gigahertz, or 1.49 billion times a second, breaking the previous record of 1.02 gigahertz achieved by a nanomachine produced by another group.

According to Gaidarzhy, during the past several decades engineers have made phenomenal advances in information technology by shrinking electronic circuitry and devices to fit onto semiconductor chips. Shrinking electronic or mechanical systems further, he says, will inevitably require new paradigms involving quantum theory. For example, these mechanical/quantum mechanical hybrids could be used for quantum computing.

Because Mohanty's nanomechanical oscillator is "large," the research team was able to attach electrical wiring to its surface in order to monitor tiny discrete quantum motion, behavior that exists in the realm of atoms and molecules.

At a certain frequency, the paddles begin to vibrate in concert, causing the central beam to move at that same high frequency, but at an increased and easily measured amplitude. Where each paddle moves only about a femtometer, roughly the diameter of an atom's nucleus, the antenna moves over a distance of one-tenth of a picometer, a tiny distance that still translates to a 100-fold increase in amplitude.

When fabricating and testing the nanomechanical device, the researchers placed the entire apparatus, including the cryostat and monitoring devices, in a state-of-the-art, copper-walled, copper-floored room. This set-up shielded the experiment from unwanted vibration noise and electromagnetic radiation that could generate from outside electrical devices, such as cell phone signals, or even the movement of subway trains outside the building.

Even with these precautions, performing such novel experiments is tricky. "When it's a new phenomenon, it's best not to be guided by expectations based on conventional wisdom," says Gaidarzhy. "The philosophy here is to let the data speak for itself."

The group carries out the experiments under extremely cold conditions, at a temperature of 110 millikelvin, which is only a tenth of a degree above the absolute zero. When cooled to such a low temperature, the nanomechanical oscillator starts to jump between two discrete positions without occupying the physical space in between, a telltale sign of quantum behavior.

In addition to Gaidarzhy, Mohanty's team consists of Guiti Zolfagharkhani, a graduate student, and Robert L. Badzey, a post-doctoral fellow in BU's Physics Department. Their paper appears in the January 28, 2005 issue of Physical Review Letters. The research was supported by grants from the National Science Foundation, U.S. Department of Defense, the American Chemical Society's Petroleum Research Fund, and the Sloan Foundation.