Researchers untangle quantum quirk

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Quantum computing has been hailed as the next leap forward for computers, promising to catapult memory capacity and processing speeds well beyond current limits. Several challenging problems need to be cracked, however, before the dream can be fully realized.

Two Arizona State University researchers, Richard Akis and Regent's Professor David Ferry, both of the electrical engineering department's Nanostructures Research Group, have proposed a solution to one of the most controversial of these conundrums and, in the process, may have taken a significant step toward realizing a quantum computing future. Their solution appeared in a special April 2008 issue of the *Journal of Physics: Condensed Matter*.

Two basic requirements of any computer are the capacity to store a value (information) and the ability to read that value. Yet even these most basic requirements present cutting-edge challenges to quantum physicists.

Today's computers store data logically as bits—ones and zeroes represented physically as positive or negative charges in a storage medium. Quantum computers, conversely, will store data logically as quantum bits, or "qubits"—an entire range of values represented physically by an electron's angle of spin.

Electrons and other subatomic particles spin like tiny tops, complete with tilt, or "precession." Since there are an infinite number of angles at which an electron can tilt, there are theoretically an infinite number of values that a qubit can store. Practically speaking, however, the number of available values will be constrained by technology and other theoretical limitations of computer science.

Currently, researchers are hard pressed to build even simple quantum computers. The problem is that quantum states are notoriously difficult to pin down and measure. Akis and Ferry's research, combined with that of former ASU colleague Jonathan Bird, could yield insights that help solve these problems.

Bird, now at University of Buffalo, has made important strides toward measuring quantum states using "entanglement," a characteristic of quantum mechanics by which two quantum particles interact at a distance. His measurement technique is based on quantum states produced by electron-electron interactions.

"This is like the 'readout' of a spin," Akis says. "It all has to do with e-e interactions, but from a remote distance."

Bird's method is only useful, however, if it has something to measure and a theory to back it up, but electron-electron interactions are complex and poorly understood. Indeed, simple quantum mechanics models often ignore electron-electron interactions entirely, instead relying on "one-electron approximation" models, which leave a number of questions unanswered.

Akis and Ferry were wrestling with one of the most controversial of these questions when they came up with a model that explained the electron-electron interactions Bird was measuring. They immediately saw the potential.

"Bird's experiment is more than a pretty measurement—there are indications that you could use this in quantum computing applications," Ferry says.

Their findings could also have important implications for quantum data storage. One way to store qubits is via a quantum point contact (QPC)—the quantum equivalent of a computer gate. Generally, the quantum behavior of electrons is represented by a stair-step graph of the conductance of these gates. Usually, the steps are either twice or half of a particular conductance value, and work just fine under a simple one-electron approximation model. Electrons are simply treated like bullets shooting through gates and not interacting with their other electrons.

These models fail to explain at least one odd case, however, which inspired the *Journal of Physics: Condensed Matter* to dedicate an entire issue to papers addressing it. The case breaks the usual pattern of QPC conductance plateaus, occurring at the 70 percent mark instead of half or twice a particular conductance value.

Akis and Ferry skipped the one-electron approximation and showed that the odd behavior at the 70 percent mark was due to interactions between up- and down-spinning electrons. This explanation means that the oddball conductance plateau can be read using Bird's method and provides an explanation for the electron-electron interactions that the method measures.

"We all use the same basic ideas—everyone agrees that you have to have e-e interactions or some manifestation of that," Akis says. "But the complete explanation is still kind of up in the air. A lot of it is based upon the model you use."

According to Akis and Ferry, electrons passing through QPCs react to them much as water would react to a series of hills and valleys. Electrons of one type of spin find it easier to clear these "hills" than electrons of the opposite spin, which mostly rebound away. Thus sorted, the particles that cleared the hills can be partially confined via a hole in the middle of the gate, resulting in a local spin polarization that can be measured via Bird's entanglement method.

"Bird's experiment is the kind of thing where you say to yourself, 'well, this could start to nail down what's really going on,'" Akis says.

Source: Arizona State University