UC SANTA BARBARA

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Physicists Discover How Fundamental Particles Lose Track of Quantum Mechanical Properties

(New Orleans, La.) –– In today's Science Express, the advance online publication of the journal Science, researchers report a series of experiments that mark an important step toward understanding a longstanding fundamental physics problem of quantum mechanics. The scientists presented their findings at the annual meeting of the American Physical Society here this week.

The problem the physicists addressed is how a fundamental particle in matter loses track of its quantum mechanical properties through interactions with its environment.

The research was performed by scientists at the California NanoSystems Institute at the University of California, Santa Barbara and the U. S. Department of Energy Ames Laboratory in Iowa.

At the quantum level things like particles or light waves behave in ways very different from what scientists expect in a human-scale world. In the quantum world, for example, an electron can exist in two places at the same time, what is called a "superposition" of states, or spin up and down at the same time.

Quantum mechanics in computing could lead to communication with no possible eavesdropping, lightning-fast database searches, and code-cracking ability.

The answer to the problem the researchers have tackled is key to unraveling how the classical world in which we live emerges from all the interacting quantum particles in matter. This scientific query surrounds the basic quantum dynamics of a single particle spin coupled to a collection, or bath, of random spins. This scenario describes the underlying behavior of a broad class of materials around us, ranging from quantum spin tunneling in magnetic molecules to nuclear magnetic resonance in semiconductors.

"We were stunned by these unexpected experimental results, and extremely excited by the ability to control and monitor single quantum states, especially at room temperature," said author David Awschalom, a professor of physics at UC Santa Barbara. Awschalom is associate director of the California NanoSystems Institute at UCSB and is the Director of the Center for

Spintronics and Quantum Computation, also at the university.

Recently the issue of how fundamental particles lose track of quantum mechanical properties through interaction with the environment has gained crucial importance in the field of quantum information. In this area, robust manipulation of quantum states promises enormous speedups over classical computation. Keeping track of the quantum phase is essential for keeping the quantum information, and insight into loss of the phase will greatly help to mitigate this process.

Experimental work on this subject has thus far been hindered by the lack of high-fidelity coherent control of a single spin in nature and the inability to directly influence the bath dynamics.

In a collaboration between physicists in Awschalom's research group at UCSB and Slava Dobrovitski, a visiting scientist from Ames Laboratory in Iowa, a series of experiments were undertaken that utilized electron spins in diamond to investigate different regimes of spin-bath interactions, and provide much information about the decoherence dynamics.

The scientists use diamond crystals to study a single electron spin tied to an adjustable collection of nearby spins. Two features of diamond that make this system viable for unprecedented investigations into the coherent dynamics are the precise optical control of a single spin that is unique to diamond, and the magnetic tunability of the spin-bath and intrabath dynamics with small permanent magnets. Their team's observations contain a number of extraordinary discoveries, such as the time-dependent disappearance and reappearance of quantum oscillations of the spins in the diamond lattice.

"To our surprise, when looking at longer times, the oscillations disappeared then re-appeared," said co-author Ronald Hanson, a postdoctoral student at UCSB during this period who is now a professor at the Kavli Institute of Nanoscience Delft, at Delft University of Technology, in the Netherlands. "At first it looked like an artifact, but repeated measurements reproduced this behavior."

The problem of a single spin coupled to a bath of spins has been the subject of an intense international research effort, as this conceptual framework describes the physical behavior of a number of real systems. Among others, these include atomic and electronic spins that are prime candidates for implementing quantum information processors and coherent spintronics devices.

A series of direct experiments coupled to theoretical simulations demonstrate that spins in diamond serve as a nearly ideal, adjustable, model of central spin.

"This work demonstrates a rare level of synergy between experiment, analytical theory, and computer simulations," said Dobrovitski. "These three constituents all agree, support, and complement each other. Together, they give a lucid qualitative picture of what happens with spin centers in diamond, and, at the same time, provide a quantitatively accurate description. This agreement is hard to anticipate in advance for such complex systems, where many nuclear and electron quantum spins interact with each other."

Studies of the quantum dynamics of spins in diamond is an emerging topic involving several leading research groups worldwide. It may also be important in the context of recent interest in possible carbon-based electronic devices employing carbon nanotubes and/or graphene.

Awschalom won the American Physical Society's Oliver E. Buckley Prize for fundamental contributions to experimental studies of quantum spin dynamics and spin coherence in condensed matter systems. Awschalom's other honors include the Agilent Europhysics Prize, the AAAS Newcomb-Cleveland Prize, the Outstanding Investigator Prize from the Materials Research Society, and the International

Magnetism Prize of the International Union of Pure and Applied Physics. He is a member of the National Academy of Sciences.

Awschalom earned his B.S. in physics at the University of Illinois at Urbana-Champaign, and his Ph.D. in experimental physics at Cornell University. He joined the UC Santa Barbara faculty as a professor of physics in 1991. His research has been chronicled in his more than 300 scientific journal articles, and has also been featured in The New York Times, The Wall Street Journal, San Francisco Chronicle, Dallas Morning News, Discover magazine, Scientific American, Physics World, and New Scientist. His research focuses on optical and magnetic interactions in semiconductor quantum structures, spin dynamics and coherence in condensed matter systems, macroscopic quantum phenomena in nanometer-scale magnets, and quantum information processing in the solid state.

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