Quantum particles find safety in numbers

October 16 2013

Ludwig Maximilian University of Munich researchers have uncovered a novel effect that, in principle, offers a means of stabilizing quantum systems against decoherence. The discovery could represent a major step forward for quantum information processing.

The laws of classical physics provide an adequate description of how our Universe behaves on the macroscopic scales that are accessible to our everyday experience. In the world of classical mechanics, the state of a physical system and its future evolution is fully determined by the instantaneous locations and velocities of its constituent particles. At the microscopic level, however, where the dynamics involves minute changes in energy – as in the case of atoms or electrons in a solid – things are very different. Here quantum mechanics reigns supreme, and the mathematical form of its laws allows even single particles to occupy states that correspond to a combination, or superposition, of distinct classical states. In this case, the position and velocity of a particle can only be described in terms of probabilities.

"This means that the system has a much greater range of possible states available to it. It is therefore far more complex and much more difficult to describe, but the complexity also offers novel opportunities for technical applications," says LMU physicist Dr. Thomas Barthel. One potential application of quantum effects is in quantum computers, which are the subject of intensive research. Miniaturization of conventional electronic computers has been so rapid that it component sizes are fast approaching the limit at which quantum phenomena must be explicitly taken into account. Current efforts focus on minimizing the perturbations introduced by such effects, but the quantum computer turns this paradigm on its head. It seeks to exploit quantum effects such as complex superpositions for [information processing](), and promises to vastly increase the efficiency of computing.

However, the controlled application of [quantum effects]() is itself subject to one severe limitation: quantum mechanical states are extremely fragile. If a quantum mechanical system is not effectively shielded from its surroundings, its interactions with the environment lead to rapid decay of its quantum properties. Thus, if one uses a probe to measure the position or velocity of a quantum particle – an atom, for example – the measurement itself forces the system to adopt a single defined state, and the superposition is irrevocably destroyed. When a [quantum system]() is coupled to its environment, something very similar occurs. The interaction with the environment is, in effect, a kind of measurement, and the information stored in the quantum system is irrevocably lost. "The system then behaves in accordance with the normal – i.e. boring – laws of classical mechanics," says Barthel.

Many-body systems can resist decoherence

Physicists refer to this phenomenon as decoherence, and it is the bane of every experimenter who wants to learn more about the quantum mechanical properties of a system or utilize them for technical applications. Until now, it was commonly accepted that the decay of quantum coherence always occurs exponentially with time. However, in their new study, instead of using a simple system such as an isolated electron or ion, Barthel and his colleague Dr. Zi Cai consider a "many-body system", such as the electrons in a solid, which consists of very large numbers of particles. "We found that, in this case, the time-dependence of the coherence decay can be qualitatively different," Barthel explains. If the system is made up of a very large collection of particles, the interactions between these particles can alter the coherence decay from the typical exponential behavior of simpler systems to a much slower power law decay. Interactions between the particles can therefore minimize the destructive influence of the environment.

The two scientists have in effect discovered a previously unsuspected fundamental effect, which is of potentially great significance tor future experiments on, and applications of, quantum states. "With our study, we have uncovered a feature with which the decoherence of a quantum system can be tuned and substantially reduced – this represents an important advance, in particular for the field of quantum information processing," as Barthel underlines. In principle, the effect can be exploited to protect the integrity of quantum information. Its discovery thus brings practical quantum computing, and simulations of complex quantum systems with the help of experimentally tractable quantum systems, a step closer to reality.

More information: *Physical Review Letters* 2013. prl.aps.org/abstract/PRL/v111/i15/e150403

Provided by Ludwig Maximilian University of Munich

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