A further advance in quantum computing

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Recent work on suppressing quantum decoherence is a step forward in the development implementation of a fully functional quantum computer. A team led by Susumu Takahashi pioneered this discovery using a new technique using the magnetic fields of single iron crystals. The results were published in *Nature* [1].

Quantum mechanics is the study of matter on the scale of the atom and smaller. It began as a separate field within physics in 1905 when Einstein published the first paper of his *annus mirabilis,* on what is now known as the photoelectric effect [2]. Using ideas inspired by earlier work by Max Planck, Einstein worked from the premise that light could be described as little packets, or quanta, of energy. The whole of quantum mechanics stems from this work on the nature of light.

The quantum physicist Richard Feynman first postulated the idea of computation using the quantum electrodynamic properties of matte, in 1982[3]. Feynman recognized that computers based on techniques derived from classical, pre-quantum theories would face inherent and insurmountable obstacles, no matter how much memory the computers utilized.

In particular, Feynman wished to directly simulate, rather than mathematically approximate, quantum properties. Instead of using random event generators used in microprocessor-based computers, which are not ever truly random, Feynman suggested that a computer could take advantage of the inherently probabilistic nature of quantum reality to simulate quantum physical events.

The basic unit of current computers is a bit. It has a value of either 0 or 1, exactly like a light switch being off or on. For each bit, a single piece of information can be processed at a time.

In quantum computers, the basic unit is a quantum bit, or qubit. Instead of a switch, a qubit is a single, fundamental particle of matter, such as a photon, the basic unit of light. The “value” of the qubit is stored within the inherent rotation of the photon, which is either positive or negative. The difference between a bit and a qubit, and this is key, is that a qubit initially has both the positive and negative values. Only when the photon is acted upon will it fall into a single state, and it will do so following the probabilistic laws of quantum mechanics. This is known as “state superposition.”

In addition to superposition, quantum computing also takes advantage of a second property of fundamental particles known as “entanglement.” It is possible to take two (or more) particles and force them to interact in such a way that even though separated, each particle acts as part of the same system. What results from this is the ability to act on a single entangled particle, which instantaneously acts on all others within the entangled system.

To see the difference between classical and quantum computers, compare 100 bits to 100 qubits. 100 bits can measure 100 pieces of information at a time. In contrast, 100 qubits can measure 2^{100} pieces of information at a time. 2^{100} approximates to 10^{30}, or a 10 followed by 30 zeros. This is about how many grains of rice would fill the volume of the solar system.

Ever since Feynman postulated quantum computing, and the physics community grasped what such machines could do, ideas have been put forth in various forms to build quantum computers. However, they have proven extremely elusive to build. In large part, this is due to the phenomenon Takahashi’s team was studying, quantum decoherence.

Being coherent in the quantum mechanical sense involves the quantum states being in alignment with each other. However, a qubit, until it is measured, is in both the positive and negative states simultaneously. How then does a quantum system ever become aligned?

This alignment is the entanglement described above.

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The problem with developing quantum computers is that it is extremely difficult to entangle more than two particles at a time without interference from the surrounding environment, which in turn results in the degrading or outright loss of the "information" stored on the qubit.

Entangled states react with the surroundings, either nearby matter or the so-called vacuum of space-time, which is not "nothing" but in fact a constant creation and annihilation of particles. These can interact with a quantum computing system, which results in the decoherence Takahashi is studying. This obstacle has prevented the creation of quantum computers that exceed the computational ability and versatility of classical computers.

Takahashi's experiment was focused on suppressing extrinsic quantum decoherence using molecular iron crystals, with each crystal consisting of eight iron atoms. While it is impossible to suppress all intrinsic quantum decoherence, for that would involve stopping the motion of matter, an absurdity, it is possible to eliminate decoherence from sources outside a quantum system (extrinsic decoherence), and most of the decoherence within the system. In particular, Takahashi and his team researched the use of the extremely high magnetic fields of the iron crystals to suppress the extrinsic sources of decoherence as well as two of the three sources of decoherence from internal environmental sources.

This research is key if we are ever able to build quantum computers, but also for our understanding of quantum mechanics itself. The reason we are unable as yet to build quantum computers is that we do not fully understand the systems which we are dealing with. Unexpected sources of motion exist that we do not necessarily know about, and in the attempt to manipulate many quantum states simultaneously, such motion makes itself known whether we understand it or not.

This research, if brought to fruition, will be a crucial step in more fully understanding quantum mechanics and will open a new path for the development of quantum computers. The theory behind quantum computers shows them to be potentially very powerful tools, capable of great progress for humanity. If they are ever built with the capacities imagined, a fully operational quantum computer would be another amazing vindication of the past century's struggle for a scientific understanding of the universe.

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