Ion Power

ATOMIC IONS PROVE THEIR QUANTUM VERSATILITY by Graham P. Collins

In their quest to build a computer that would *take advantage* of the *weirdness* of quantum mechanics, physicists are pursuing a number, of disparate technologies, including superconducting devices, photonbased systems, quantum dots, spintronics and nuclear magnetic resonance of molecules. In recent months, however, teams working with trapped atomic ions have demonstrated several landmark feats that the other approaches will be hard-pressed to match.

A quantum computer operates on quantum bits, or qubits, instead of ordinary bits. A qubit can be not just 0 or 1 but also a superposition of the two, in which proportions of zero-ness and one-ness are combined in a single state.

An important class of multiqubit superpositions are *entangled* states. In these configurations, the state of each qubit is linked in a subtle way to the state of its companions, a linkage that Albert Einstein disparaged as “spooky action at a distance.” For example, in a so-called Schrödinger cat state, all the qubits will give the same result-0 or l-on being measured, even though the choice between 0 and 1 is *totally random*. (The name comes from the famous thought experiment in which 0 and 1 correspond to the cat being dead or alive and the individual “qubits” are all the particles in the cat's body.)

Cat states are a fundamental *building block* of techniques for correcting errors in qubits. Such errors *inevitably* plague all the standard approaches to quantum computation, because states of qubits are exceedingly fragile.

Researchers at the National Institute of Standards' and Technology in Boulder, Colorado., led by David J. Wineland and Dietrich Leibfried, have now created cat states involving four, five and six beryllium ions. An electromagnetic *trap* holds the ions in a row in a vacuum, and lasers *manipulate* their states. The team estimates that their six-ion cat states last for approximately 150 microseconds.

In Austria, Rainer Blatt and Hartmut Haeffner of the University of Innsbruck and their colleagues relied on a similar technique to produce an entangled state of eight calcium ions. In this experiment a “W state” was created, not a cat state. A *W* state is in many ways more robust than a cat state. For example, an ion can be lost from a W state and the remaining ions will still be in a W state. Losing an ion from a cat state spoils the entire state. ,

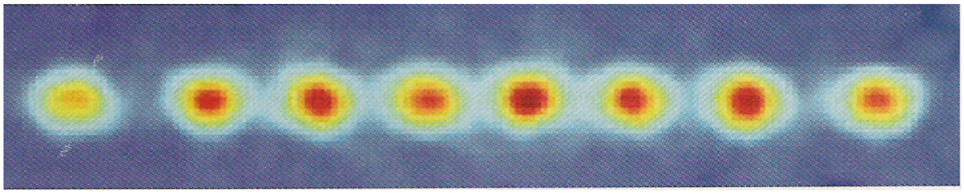
An *important feature* of both experiments is that in principle the techniques can *incorporate* larger numbers of ions. An *impediment* to scaling up these approaches, however, was that the quality of the entangled state decreased as the number of ions increased. To reduce this error, the scientists might adjust the details of the laser pulses, use different states of the ions to represent 0 and 1, or work with a different ion species altogether.

For a quantum computer to be of use, one must not only create special qubit states but also manipulate them in ways that preserve their quantum characteristics. That is, one must run quantum algorithms on the computer. A group at the University of Michigan at Ann Arbor led by Christopher Monroe and Kathy-Anne Brickman has now demonstrated an algorithm known as Grover's quantum search on a system of two trapped cadmium ions.

The search algorithm rummages through a database with entries in random order. Searching for a particular item would usually demand the examination of every entry. The quantum search algorithm is magically faster because the quantum computer can *poll* all the database entries at once in a superposition. The speedup becomes more dramatic for larger data bases. For example, a million-entry database would take only about 1,000 quantum lookups instead of the full million.

The Ann Arbor experiment operated on the equivalent of a four-entry database, the four entries being represented by two qubits. The researchers say that their system can be scaled up to larger numbers of qubits.

With results coming so thick and fast, it is no wonder that, as Monroe says, “many feel that ion traps are *well ahead* of other technology in the quest to build a large-scale quantum computer.”



Entangled : Eight calcium ions held together in a trap are in a special quantum condition known as a *W* entangled state, in which their properties are subtly correlated. Such states are of use for error-correction schemes in quantum computers. Entangled states become harder to create and maintain as the number of particles increases.

NEED TO KNOW:

Experiments with atomic ions involve custom-built, bulky electromagnetic traps to confine the ions in a vacuum. Though fine for experiments with a small number of ions, they are utterly impractical for the large-scale system that a quantum computer would need to be of any significant use. Now University of Michigan at Ann Arbor researchers Christopher Monroe, Daniel Stick and their co-workers have demonstrated a 100-micron-size ion trap on a semiconductor chip. They used their chip to trap a single cadmium ion and move it to different locations in the trap by applying electrical signals to electrodes. The trap was built using standard lithography techniques, so, Monroe says, it could be scaled up to include hundreds of thousands of electrodes using existing technology.

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Crater Jumper

Hopping Probe May Hunt For Ice On The Moon, By Mark Alpert

The entire future of human space exploration may rest on a patch of lunar ice. For the past two years NASA has focused on designing a new crew vehicle and launch system that could return astronauts to the moon by 2018. The agency's ultimate goal is to establish a permanent lunar base and use the program's technology to prepare a human mission to Mars. But the grand plan hinges on a risky prediction : that NASA will find water ice in a permanently shadowed crater basin at one of the moon's poles.

Plentiful ice deposits would be a boon for lunar colonists, who could use the water for life support or convert it to hydrogen and oxygen rocket fuel. And two orbiters sent to the moon in the 1990s, Clementine and Lunar Prospector, found evidence of ice in perpetually shadowed polar areas where consistently frigid temperatures would preserve the water carried to the moon by cornet and meteorite impacts. But some scientists have disputed Clementine's radar data, and the anomalous neutron emissions observed by Lunar Prospector could have been caused by atomic hydrogen in the lunar soil instead of ice.

In an attempt to settle the question, NASA plans launch the Lunar Reconnaissance Orbit (LRO) in 2008. Traveling in a polar orbit only 50 kilometers above the moon's surface, the one-ton, $400-million probe will train a high-resolution neutron sensor on the suspected ice deposits to determine their locations more precisely. The LRO will also carry a radiometer to measure surface temperatures, an ultraviolet detector to peer into the shadowed crater basins, and a laser altimeter and camera to map the polar regions and to scout possible landing sites.

But because the ice is probably buried and mixed with the lunar dirt, NASA will need to land a probe that could dig up and analyze soil samples. This mission, scheduled for 2011, is a challenging one given that instruments operating in shadowed areas cannot use solar power. The craft could land at a sunlit site and send a battery-powered rover into a dark crater, but the batteries would quickly die. A radioisotope thermal generator could provide electricity using heat from plutonium decay, but NASA is leaning against this option because it is expensive and controversial.

Another idea under consideration is sending a probe that could hop from place to place on the lunar surface by restarting its landing rockets, which could lift the craft up to 100 meters above its original landing site and move it to another spot in the crater basin to hunt for ice. Investigating more than one site is crucial because the ice may be unevenly distributed. Yet another alternative would be to fire ground-penetrating instruments at several places in the shadowed basin, either from a lander at the crater's rim or from an orbiting craft.

The major pitfall of NASA's strategy is the possibility that its probes will find no ice or discover that the ice is too sparse to be a useful resource. '”I'm a little worried that they're counting too much on finding water in a usable form,” says Wesley T. Huntress, Jr., a former NASA science chief who now leads the Carnegie Institution's Geophysical Laboratory. If extracting ice from the moon proves infeasible, the space agency may have to choose new landing sites and exploration goals for the human missions. But NASA believes the robotic craft will be worthwhile even if they do not find ice. Says Mark Borkowski, head of the Robotic Lunar Exploration Program: “We can't help but get science from these measurements.”