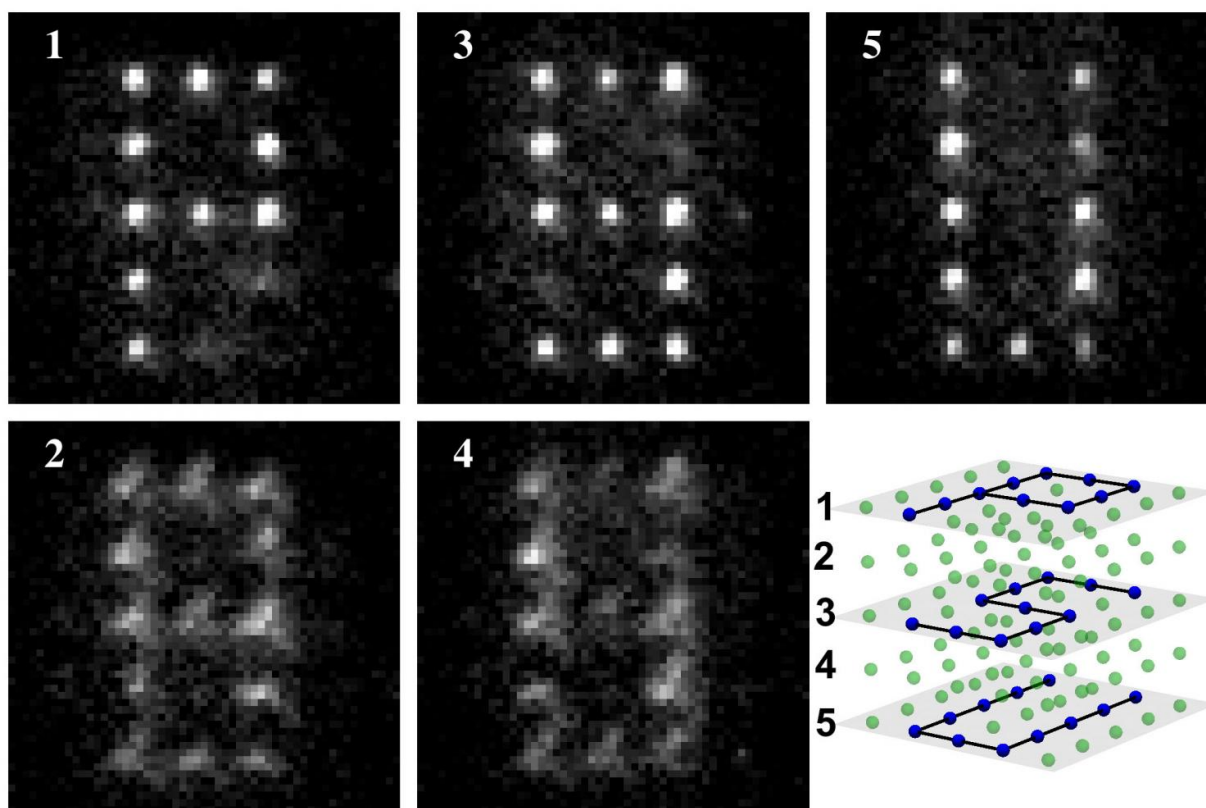


New, better way to build circuits for world's first useful quantum computers

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The research team led by David Weiss at Penn State University performed a specific single quantum operation on individual atoms in a P-S-U pattern on three separate planes stacked within a cube-shaped arrangement. The team then used light beams to selectively sweep away all the atoms that were not targeted for that operation. The scientists then made pictures of the results by successively focusing on each of the planes in the cube. The photos, which are the sum of 20 implementations of this process, show bright spots where the atoms are in focus, and fuzzy spots if they are out of focus in an adjacent plane

-- as is the case for all the light in the two empty planes. The photos also show both the success of the technique and the comparatively small number of targeting errors. Credit: David Weiss lab, Penn State University

The era of quantum computers is one step closer as a result of research published in the current issue of the journal *Science*. The research team has devised and demonstrated a new way to pack a lot more quantum computing power into a much smaller space and with much greater control than ever before. The research advance, using a 3-dimensional array of atoms in quantum states called quantum bits—or qubits—was made by David S. Weiss, professor of physics at Penn State University, and three students on his lab team. He said "Our result is one of the many important developments that still are needed on the way to achieving quantum computers that will be useful for doing computations that are impossible to do today, with applications in cryptography for electronic data security and other computing-intensive fields."

The new technique uses both laser light and microwaves to precisely control the switching of selected individual qubits from one quantum state to another without altering the states of the other atoms in the cubic array. The new technique demonstrates the potential use of atoms as the building blocks of circuits in future quantum computers.

The scientists invented an innovative way to arrange and precisely control the qubits, which are necessary for doing calculations in a quantum computer. "Our paper demonstrates that this novel approach is a precise, accurate, and efficient way to control large ensembles of qubits for quantum computing," Weiss said.

The paper in *Science* describes the new technique, which Weiss's team plans to continue developing further. The achievement also is expected

to be useful to scientists pursuing other approaches to building a quantum computer, including those based on other atoms, on ions, or on atom-like systems in 1 or 2 dimensions. "If this technique is adopted in those other geometries, they would also get this robustness," Weiss said.

To corral their quantum atoms into an orderly 3-D pattern for their experiments, the team constructed a lattice made by beams of light to trap and hold the atoms in a cubic arrangement of five stacked planes—like a sandwich made with five slices of bread—each with room for 25 equally spaced atoms. The arrangement forms a cube with an orderly pattern of individual locations for 125 atoms. The scientists filled some of the possible locations with qubits consisting of neutral cesium atoms—those without a positive or a negative charge. Unlike the bits in a classical computer, which typically are either zeros or ones, each of the qubits in the Weiss team's experiment has the difficult-to-imagine ability to be in more than one state at the same time—a central feature of quantum mechanics called quantum superposition.

Weiss and his team then use another kind of light tool—crossed beams of laser light—to target individual atoms in the lattice. The focus of these two laser beams, called "addressing" beams, on a targeted atom shifts some of that atom's energy levels by about twice as much as it does for those of any of the other atoms in the array, including those that were in the path of one of the addressing beams on its way to the target. When the scientists then bathe the whole array with a uniform wash of microwaves, the state of the atom with the shifted energy levels is changed, while the states of all the other atoms are not.

"We have set more qubits into different, precise quantum superpositions at the same time than in any previous experimental system," Weiss said. The scientists also designed their system to be very insensitive to the exact details of the alignments or the power of those light beams they use—which Weiss said is a good thing because "you don't want to be

dependent upon exactly what the intensity of the light is or exactly what the alignment is."

One of the ways that the scientists demonstrated their ability to change the quantum state of individual atoms was by changing the states of selected atoms in three of the stacked planes within the cubic array in order to draw the letters P, S, and U—the letters that represent Penn State University. "We changed the quantum superposition of the PSU atoms to be different from the quantum superposition of the other atoms in the array," Weiss said. "We have a pretty high-fidelity system. We can do targeted selections with a reliability of about 99.7%, and we have a plan for making that more like 99.99%."

Among the goals that Weiss has for his team's future research is to get the qubits to "have entangled quantum wave functions where the state of one particle is implicitly correlated with the state of the other particles around it." Weiss said that this entangled connection between qubits is a critical element needed for [quantum computing](#). He said he hopes that building on the techniques demonstrated in his team's prototype system eventually will enable his lab to demonstrate high-quality entangling operations for [quantum](#) computing. "Filling the cube with exactly one atom per site and setting up entanglements between [atoms](#) at any of the sites that we choose are among our nearer-term research goals," Weiss said.

More information: Y. Wang et al. Single-qubit gates based on targeted phase shifts in a 3D neutral atom array, *Science* (2016). [DOI: 10.1126/science.aaf2581](https://doi.org/10.1126/science.aaf2581)

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