A new design for quantum computers

February 15 2024

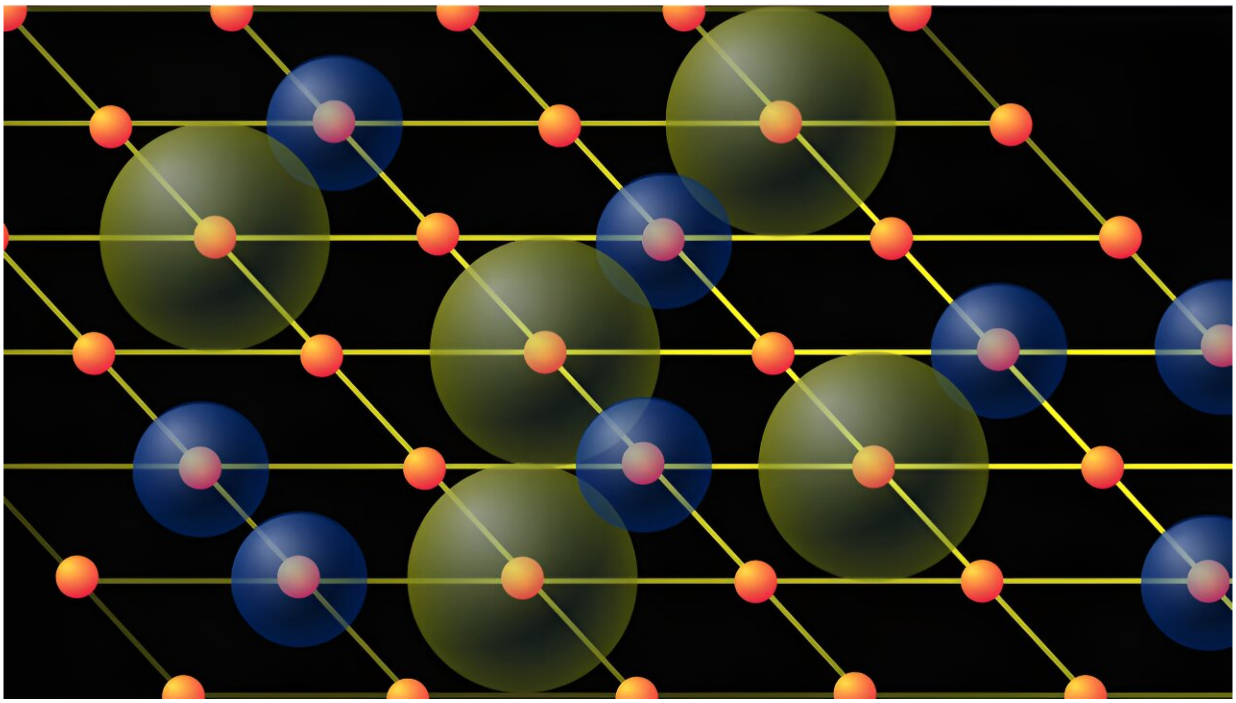

Illustration of a quantum simulator with atoms trapped into a square lattice with lasers. The small spheres at the corners are atoms in their lowest energy state. The ones inside a blue sphere are exited (higher in energy) by the first laser, the ones inside yellow spheres are excited by the second laser (even more higher in energy). Credit: TU Delft

Creating a quantum computer powerful enough to tackle problems we cannot solve with current computers remains a big challenge for quantum physicists. A well-functioning quantum simulator—a specific type of quantum computer—could lead to new discoveries about how the world works at the smallest scales.

Quantum scientist Natalia Chepiga from Delft University of Technology has developed a guide on how to upgrade these machines so that they can simulate even more complex quantum systems. The study is now published in *Physical Review Letters*.

"Creating useful quantum computers and quantum simulators is one of the most important and debated topics in quantum science today, with the potential to revolutionize society," says researcher Natalia Chepiga. Quantum simulators are a type of quantum computer. Chepiga explains, "Quantum simulators are meant to address open problems of quantum physics to push our understanding of nature further. Quantum computers will have wide applications in various areas of social life, for example, in finances, encryption, and data storage."

Steering wheel

"A key ingredient of a useful quantum simulator is the possibility to control or manipulate it," says Chepiga. "Imagine a car without a steering wheel. It can only go forward but cannot turn. Is it useful? Only if you need to go in one particular direction; otherwise, the answer will be 'no!'. If we want to create a quantum computer that will be able to discover new physics phenomena in the near future, we need to build a 'steering wheel' to tune into what seems interesting. In my paper, I propose a protocol that creates a fully controllable quantum simulator."

The protocol is a recipe—a set of ingredients that a quantum simulator should have to be tunable. In the conventional setup of a quantum simulator, rubidium (Rb) or cesium (Cs) atoms are targeted by a single laser. As a result, these particles will take up electrons and thereby become more energetic; they become excited.

"I show that if we were to use two lasers with different frequencies or colors, thereby exciting these atoms to different states, we could tune the quantum simulators to many different settings," Chepiga explains.

The protocol offers an additional dimension of what can be simulated. "Imagine that you have only seen a cube as a sketch on a flat piece of paper, but now you get a real 3D cube that you can touch, rotate, and explore in different ways," Chepiga continues. "Theoretically, we can add even more dimensions by bringing in more lasers."

Simulating many particles

"The collective behavior of a quantum system with many particles is extremely challenging to simulate," Chepiga explains. "Beyond a few dozen particles, modeling with our usual computer or a supercomputer has to rely on approximations." When taking the interaction of more particles, temperature, and motion into account, there are simply too many calculations to perform for the computer.

Quantum simulators are composed of quantum particles, which means that the components are entangled. "Entanglement is some sort of mutual information that quantum particles share between themselves. It is an intrinsic property of the simulator and therefore allows to overcome this computational bottleneck."

More information: Natalia Chepiga, Tunable Quantum Criticality in Multicomponent Rydberg Arrays, *Physical Review Letters* (2024). DOI: 10.1103/PhysRevLett.132.076505. On *arXiv*: DOI: 10.48550/arxiv.2308.12838

Provided by Delft University of Technology