Zapping quantum materials with lasers tells us how atoms relate

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Credit: Johannes Plenio on Pexels

Phase transitions are a fundamental piece of physics and chemistry. We're all familiar with different phases of water, for example, but this idea of a system of particles changing what it looks like and how it behaves is really ubiquitous in science. And while we know the outcome of water changing into ice, the precise process leads to many different kinds of ice: sometimes ice is transparent and other times not, and the difference has to do with how you freeze it. Thus, studying how a phase transition happens tells us a lot about fundamental physics, and about the resulting phases on both sides.

At the quantum physics level, the same idea applies. We can see the change of a system from one state to another as we slowly change the temperature across the critical temperature; for example, we can see that the material becomes hard, just like we can watch ice form. But we don't see the details on an atomic level as they happen. In this work, we were able to overcome that and open a window onto how the atoms are rearranging themselves from one phase of the system to another on atomic (picosecond) time scales.

In this particular work, we studied $CeTe_3$. It is part of a larger class of materials, the rare earth tri-tellurides. If you look at its atomic structure at high temperatures, this material is built like a stacked net of squares. As the temperature decreases, the squares turn into rectangles. There are two directions this can happen in (let's call them A and B), but the material only picks one. Which one depends on happenstance—local stresses and strains in the material caused by defects.

In the experiment, we used ultrashort intense laser pulses to briefly take the system out of its "A" rectangle state and watched how it tried to reform. Since there is no particularly strong driving force towards either rectangle state, the system formed both A and B rectangles. As one of the rectangles (on picosecond atomic timescales) dominates the other, small puddles of the "wrong" state remain, which are difficult to get rid of and last for nanoseconds (100x longer).

These results tell us about fundamental aspects of how phase changes happen, how various parts of the materials "talk" to each other to align their atoms so the patterns match up, and what the energy landscape is on which all of this happens.

When we know what is happening with quantum materials and how they change their state on the atomic level, we can use that knowledge to develop new and better devices, like MRI machines, and better computer memory.

More information: Faran Zhou et al. Nonequilibrium dynamics of spontaneous symmetry breaking into a hidden state of charge-density wave, *Nature Communications* (2021). DOI: 10.1038/s41467-020-20834-5

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