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Physics

Quantum theory is challenging long-standing ideas about entropy

A mathematical study finds that three definitions of what it means for entropy to increase, which have previously been considered equivalent, can produce different results in the quantum realm

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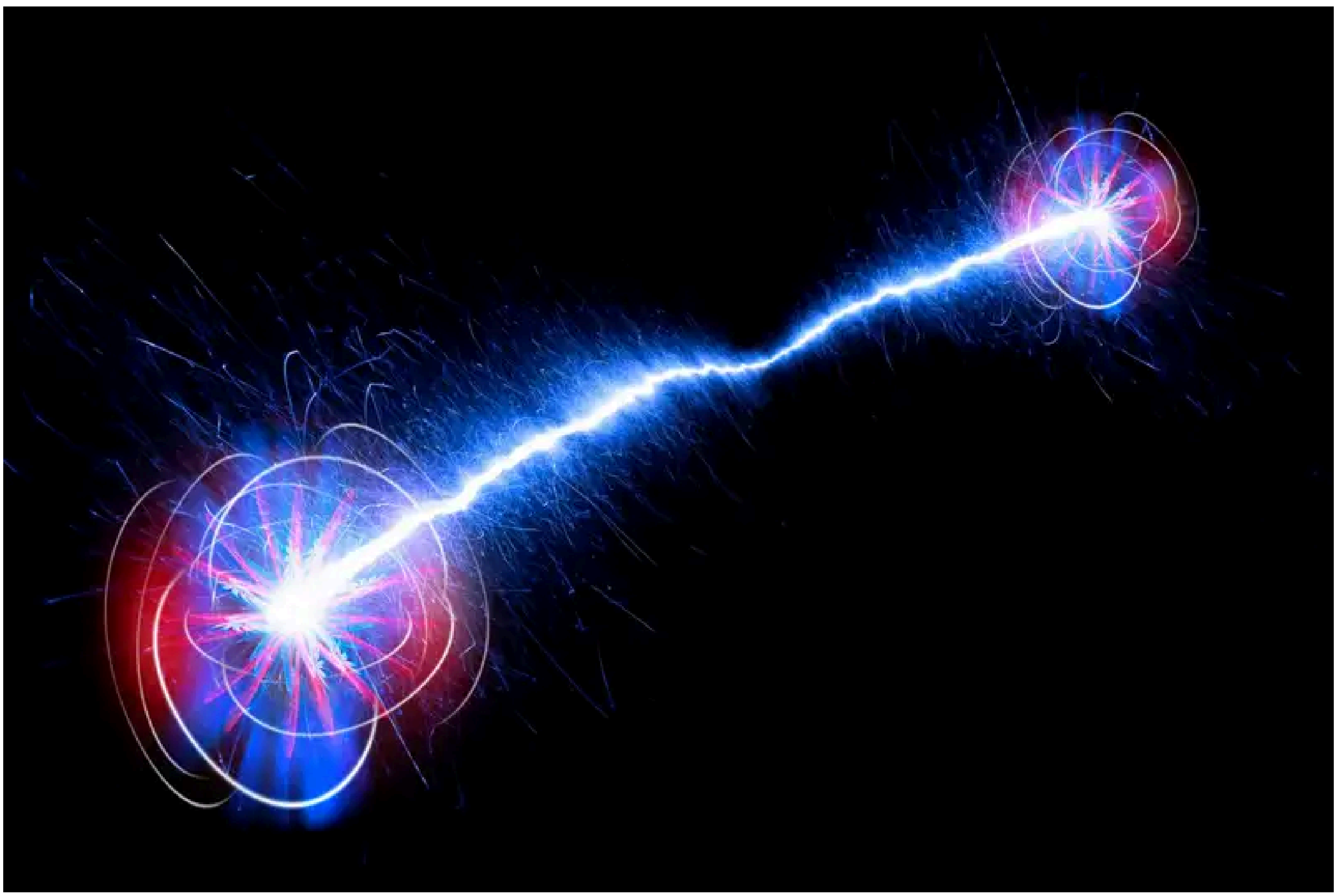

Quantum theory is poking holes in our understanding of entropy
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Measuring disorder in the quantum realm is creating a bit of a mess. A mathematical study found that three different definitions of entropy that were previously thought to be equivalent don't always match for quantum objects.

When two objects are connected – say a container of hot gas is linked to a colder gas reservoir – the entropy of the colder one can increase because the two will exchange quantities like particles and heat. For almost 200 years, physicists have used the same set of equations to calculate just how much entropy is produced in every such process. But they may have been oblivious to quantum complications 🔗 /article/2450758-certain-quantum-systems-may-be-able-to-defy-entropys-effects-forever/, says Nicole Yunger Halpern 🔗 https://www.nist.gov/people/nicole-halpern at the National Institute of Standards and Technology in Maryland. She and her colleagues wanted to make them clear.

They focused on the quantum phenomenon of "noncommuting quantities", the idea that the properties of a quantum object, as determined through measurements, can depend on the order in which those measurements are made.

More conventionally, we think of most quantities as "commuting"– if you measure a rectangle's length and then its width, you'll get the same results as when you measure the width before the length. Or take the example of the two connected containers of gas, which are exchanging particles and heat. It doesn't matter which property you measure first – the number of particles or the amount of heat that passed between them – because these two quantities commute.

But properties like quantum spin 🔗 /lastword/mg25834451-300-so-much-in-the-universe-spins-could-the-universe-itself-be-spinning/ are trickier. For instance, a single particle can have several types of spin, such as vertical and horizontal, and these don't commute 🔗 /article/2372659-weird-particle-that-remembers-its-past-discovered-by-quantum-computer/. So, when two objects are exchanging spins, measuring the amount of horizontal spin then the amount of vertical spin will produce a different value than measuring them in reverse order.

"A measurement can tell us that the system has some amount of this particular quantity, but it totally messes up the amount of the other quantity," says Yunger Halpern.

Using such noncommuting measurements to determine changes in a system's properties, such as its entropy, is thus more complicated. In fact, when the researchers used three different equations for entropy production – which give the same answer when used for commuting quantities – they found that they disagreed for the noncommuting case.

Each equation corresponded to a specific conceptual understanding of entropy; for instance, entropy as a measure of disorder versus entropy as a measure of how hard it would be to reverse the heat exchange process. Their inequivalence may have repercussions for how we understand entropy /article/2338655-engine-based-on-maxwells-demon-concept-may-help-us-understand-entropy/ overall.

"We kept discussing what would happen if we wrote down a checklist of properties that entropy production should have. And we couldn't find a unified definition that would satisfy it," says Gabriel Landi https://www.pas.rochester.edu/people/faculty/landi-gabriel/index.html at the University of Rochester in New York, who worked on the project.

Shayan Majidy https://lukin.physics.harvard.edu/people/shayan-majidy at Harvard University says that, historically, whenever physicists removed the assumption that quantities must commute, many well-established mathematical models – for studies of heat, entropy and energy or thermodynamics /article/mg26134721-800-molecular-storms-review-unsung-physics-helps-unpick-lifes-complexity/ – had to be adjusted. "It's kind of like a Jenga tower: you pull out one block and all the other blocks fall down," he says.

In his view, it is too early to know whether some more unified definition of entropy production can still be formulated. But he takes the new study as a note of caution for future analyses in the quantum realm. "Based on what you're studying, you now have to be careful when you're picking out the definition. In the more classical case, you don't have to worry about that," says Majidy.

Yunger Halpern's team is interested in testing this in practice. They are already collaborating on an experiment with quantum bits, like those used in quantum computers /article-topic/quantum-computing/. And they are gearing up for more mathematical work. "I think that we need to now go around to absolutely every facet of thermodynamics and ask, what happens here [now]?" she says.