Physicists prove that it's impossible to cool an object to absolute zero

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(Phys.org)—In 1912, chemist Walther Nernst proposed that cooling an object to absolute zero is impossible with a finite amount of time and resources. Today this idea, called the unattainability principle, is the most widely accepted version of the third law of thermodynamics—yet so far it has not been proved from first principles.

Now for the first time, physicists Lluís Masanes and Jonathan Oppenheim at the University College of London have derived the third law of thermodynamics from first principles. After more than 100 years, the result finally puts the third law on the same footing as the first and second laws of thermodynamics, both of which have already been proved.

"The goal of fundamental physics is to derive all the laws of nature and to describe all phenomena by only assuming a small set of principles (like quantum mechanics, the Standard Model of particle physics, etc.)," Masanes told *Phys.org*. "And that's what we do. In addition, this derivation unveils the strong connections among the limitations of cooling, the positivity of the heat capacity, the reversibility of microscopic dynamics, etc. Personally, I love that the whole of thermodynamics (including the third law) has been derived from more fundamental principles."

To prove the third law, the physicists used ideas from computer science and quantum information theory. There, a common problem is to determine the amount of resources required to perform a certain task. When applied to cooling, the question becomes how much work must be done and how large must the cooling reservoir be in order to cool an object to absolute zero (0 Kelvin, -273.15°C, or -459.67°F)?

The physicists showed that cooling a system to absolute zero requires either an infinite amount of work or an infinite reservoir. This finding is in agreement with the widely accepted physical explanation of the unattainability of absolute zero: As the temperature approaches zero, the system's entropy (disorder) approaches zero, and it is not possible to prepare a system in a state of zero entropy in a finite number of steps.

The new result led the physicists to a second question: If we can't reach absolute zero, then how close can we get (with finite time and resources)? It turns out that the answer is closer than might be expected. The scientists showed that lower temperatures can be obtained with only a modest increase of resources. Yet they also showed that there are limits here, as well. For example, a system cannot be cooled exponentially quickly, since this would result in a negative heat capacity, which is a physical impossibility.

One of the nice features of the new proof is that it applies not only to large, classical systems (which traditional thermodynamics usually deals with), but also to quantum systems and to any conceivable type of cooling process.

For this reason, the results have widespread theoretical implications. Cooling to very low temperatures is a key component in many technologies, such as quantum computers, quantum simulations, and high-precision measurements. Understanding what it takes to get close to absolute zero could help guide the development and optimization of future cooling protocols for these applications.

"Now that we have a better understanding of the limitations of cooling, I would like to optimize the existing cooling methods or come up with new ones," Masanes said.

More information: Lluís Masanes and Jonathan Oppenheim. "A general derivation and quantification of the third law of thermodynamics." *Nature Communications*. DOI: 10.1038/ncomms14538

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