Thermodynamics as a resource theory: versions of the second law(s)

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In this tutorial, I will give an introduction to the resource-theoretic formulation of (quantum) thermodynamics, with an emphasis on the repeatable use of resources and versions of the second law. After describing fundamental results like the difference between extractable work and work of formation[1], I will illustrate how the introduction of catalysts leads to a formulation of "many second laws"[2]. However, it turns out that allowing correlations to build up restores the original form of the second law, and gives the nonequilibrium free energy a fluctuation-free operational interpretation for single and strongly correlated quantum systems, without thermodynamic limit or averaging[3]. I will also explain how the presence of quantum coherence leads naturally to questions about the repeatable use of quantum references frames, in particular clocks, and describe a recent no-broadcasting result that tells us that clocks must necessarily degrade[4] upon use, restricting "catalytic coherence" results like the one by J. Åberg in finite dimensions.

[1]M. Horodecki and J. Oppenheim, Nat. Comm. **4**, 2059 (2013).
[2]F. Brandão, M. Horodecki, N. Ng, J. Oppenheim, and S. Wehner, PNAS **12**, 3275 (2015).
[3]M. P. Müller, Phys. Rev. X **8**, 041051 (2018).
[4]M. Lostaglio and M. P. Müller, to appear in Phys. Rev. Lett. (2019).