



Title: **Thermodynamics in the Complex Plane**
— How the imaginary comes real

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Abstract

In two foundational papers published in 1952, Lee and Yang established rigorously the connection between the analytic properties of thermodynamic functions and phase transitions. In particular, they proved that the zero points of the partition functions of lattice gases (called Lee-Yang zeros) are all located along the unit circle in the complex plane of fugacity (Lee-Yang theorem), or equivalently, along the imaginary axis of magnetic field for ferromagnetic Ising models. The Lee-Yang zeros, however, have never been observed in experiments since the complex parameters are generally regarded as unphysical. Recently, we discovered that the quantum coherence of a probe spin coupled to a bath is equivalent to the partition function of the bath, with the evolution time corresponding to an imaginary physical parameter [1]. This makes it possible to experimentally study Lee-Yang zeros in particular and thermodynamics for complex parameters in general. Based on this idea, Lee-Yang zeros have been experimentally observed for the first time [2]. We further find that the Yang-Lee edges, i.e., the starting and ending points of the Lee-Yang zeros, lead to a new type of phase transitions, namely, time-domain phase transitions, which manifest themselves in the probe coherence as sudden changes when the bath approaches to the thermodynamic limit [1]. Starting from that, we developed a systematic theory on phase transitions in the complex plane of physical parameters, which can be measured as abrupt changes of the probe coherence evolutions even at temperatures higher than the critical points for conventional phase transitions [3]. We also established the thermodynamic holography in which the thermodynamic properties of a system in an area of physical parameters are fully determined by the properties along the boundary. We expect a wealth of new, experimentally verifiable physics to be explored in the complex plane of physical parameters.

References:

1. Bo-Bo Wei & R. B. Liu, Physical Review Letters 109, 185701 (2012). *Lee-Yang Zeros and Critical Times in Decoherence of a Probe Spin Coupled to a Bath*
2. Xinhua Peng, Hui Zhou, Bo-Bo Wei, Jiangyu Cui, Jiangfeng Du, Ren-Bao Liu, arXiv:1403.5383 (2014). *Observation of Lee-Yang zeros*
3. Bo-Bo Wei, Shao-Wen Chen, Hoi-Chun Po, Ren-Bao Liu, arXiv:1401.3808 (2014). *Phase transitions in the complex plane of physical parameters*