Testing the Structure of Multipartite Entanglement with Bell Inequalities

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We show that the rich structure of multipartite entanglement can be tested following a device-independent approach. Specifically we present Bell inequalities for distinguishing between different types of multipartite entanglement, without placing any assumptions on the measurement devices used in the protocol, in contrast with usual entanglement witnesses. We first address the case of three qubits and present Bell inequalities that can be violated by *W* states but not by Greenberger-Horne-Zeilinger states, and vice versa. Next, we devise 'subcorrelation Bell inequalities' for any number of parties, which can provably not be violated by a broad class of multipartite entangled states (generalizations of Greenberger-Horne-Zeilinger states), but for which violations can be obtained for *W* states. Our results give insight into the nonlocality of *W* states. The simplicity and robustness of our tests make them appealing for experiments.

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Thermalization in Nature and on a Quantum Computer

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In this work, we show how Gibbs or thermal states appear dynamically in closed quantum many-body systems, building on the program of dynamical typicality. We introduce a novel perturbation theorem for physically relevant weak system-bath couplings that is applicable even in the thermodynamic limit. We identify conditions under which thermalization happens and discuss the underlying physics. Based on these results, we also present a fully general quantum algorithm for preparing Gibbs states on a quantum computer with a certified runtime and error bound. This complements quantum Metropolis algorithms, which are expected to be efficient but have no known runtime estimates and only work for local Hamiltonians.

Operational Significance of Discord Consumption: Theory and Experiment

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Coherent interactions that generate negligible entanglement can still exhibit unique quantum behaviour. This observation has motivated a search beyond entanglement for a complete description of all quantum correlations. Quantum discord is a promising candidate [5, 6]. Here, we demonstrate that under certain measurement constraints, discord between bipartite systems can be consumed to encode information that can only be accessed by coherent quantum interactions. The inability to access this information by any other means allows us to use discord to directly quantify this 'quantum advantage'. We experimentally encode information within the discordant correlations of two separable Gaussian states. The amount of extra information recovered by coherent interaction is quantified and directly linked with the discord consumed during encoding. No entanglement exists at any point of this experiment. Thus we introduce and demonstrate an operational method to use discord as a physical resource.

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"Hyperbits": The information quasiparticles

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Information theory has its particles, bits and qubits, just as physics has electrons and photons. However, in physics we have a special category of objects with no clear counterparts in information theory: quasiparticles. They are introduced to simplify complex emergent phenomena making otherwise very difficult calculations possible and providing additional insight into the inner workings of the system. We show that we can adopt a similar approach in information theory. We introduce the hyperbits, information quasiparticles which we prove to be a resource equivalent to entanglement and classical communication, and we give examples of how they can be used to simplify calculations and get more insight into communication protocols.

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The Complete Quantum Cheshire Cat

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We show that a physical property can be *entirely* separated from the object it belongs to, hence realizing a complete quantum Cheshire cat. Our setup makes use of a type of quantum state of particular interest, namely an entangled pre- and post-selected state, in which the pre- and post-selections are entangled with each other. Finally we propose a scheme for the experimental implementation of these ideas.

Is a System's Wave Function in One-to-One Correspondence with Its Elements of Reality?

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Although quantum mechanics is one of our most successful physical theories, there has been a long-standing debate about the interpretation of the wave function—the central object of the theory. Two prominent views are that (i) it corresponds to an element of reality, i.e., an objective attribute that exists before measurement, and (ii) it is a subjective state of knowledge about some underlying reality. A recent result [M. F. Pusey, J. Barrett, and T. Rudolph, arXiv:1111.3328] has placed the subjective interpretation into doubt, showing that it would contradict certain physically plausible assumptions, in particular, that multiple systems can be prepared such that their elements of reality are uncorrelated. Here we show, based only on the assumption that measurement settings can be chosen freely, that a system's wave function is in one-to-one correspondence with its elements of reality. This also eliminates the possibility that it can be interpreted subjectively.

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Extracting Dynamical Equations from Experimental Data is NP Hard

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The behavior of any physical system is governed by its underlying dynamical equations. Much of physics is concerned with discovering these dynamical equations and understanding their consequences. In this Letter, we show that, remarkably, identifying the underlying dynamical equation from any amount of experimental data, however precise, is a provably computationally hard problem (it is NP hard), both for classical and quantum mechanical systems. As a by-product of this work, we give complexity-theoretic answers to both the quantum and classical embedding problems, two long-standing open problems in mathematics (the classical problem, in particular, dating back over 70 years).

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Continuous Quantum Hypothesis Testing

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I propose a general quantum hypothesis testing theory that enables one to test hypotheses about any aspect of a physical system, including its dynamics, based on a series of observations. For example, the hypotheses can be about the presence of a weak classical signal continuously coupled to a quantum sensor, or about competing quantum or classical models of the dynamics of a system. This generalization makes the theory useful for quantum detection and experimental tests of quantum mechanics in general. In the case of continuous measurements, the theory is significantly simplified to produce compact formulas for the likelihood ratio, the central quantity in statistical hypothesis testing. The likelihood ratio can then be computed efficiently in many cases of interest. Two potential applications of the theory, namely, quantum detection of a classical stochastic waveform and test of harmonic-oscillator energy quantization, are discussed.

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Cooling by Heating: Very Hot Thermal Light Can Significantly Cool Quantum Systems

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We introduce the idea of actually cooling quantum systems by means of incoherent thermal light, hence giving rise to a counterintuitive mechanism of ‘‘cooling by heating.’’ In this effect, the mere incoherent occupation of a quantum mechanical mode serves as a trigger to enhance the coupling between other modes. This notion of effectively rendering states more coherent by driving with incoherent thermal quantum noise is applied here to the optomechanical setting, where this effect occurs most naturally. We discuss two ways of describing this situation, one of them making use of stochastic sampling of Gaussian quantum states with respect to stationary classical stochastic processes. The potential of experimentally demonstrating this counterintuitive effect in optomechanical systems with present technology is sketched.

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