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Reinforcement Learning in Phases of Quantum Control

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The ability to prepare a physical system in a desired quantum state is central to many areas of physics such as nuclear magnetic resonance, cold atoms, and quantum computing. Preparing states quickly and with high fidelity remains a formidable challenge. In this work we implement cutting-edge Reinforcement Learning (RL) techniques to find short, high-fidelity driving protocols from an initial to a target state in non-integrable single-particle and many-body quantum spin systems. This movie displays the learning process for the case of a single spin. The quantum state preparation problem, viewed as an optimization problem, is shown to exhibit examples of prototypical equilibrium phase transitions in classical macroscopic systems: both first and second order phase transitions, a glass phase, and symmetry breaking, as a function of the protocol duration. These control phase transitions, present even in low-dimensional clean quantum systems, are classical yet of non-equilibrium nature, and carry far-reaching consequences for manipulating quantum states.