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Photon Thermalization in Driven Open Quantum Systems

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Photons are the most accessible massless particles known. However, their lack of mass and extremely weak interactions mean that typically the thermal description of light is that of blackbody radiation. While lasers provide a severe example of a nonequilibrium problem of light, recent interests in the near-equilibrium physics of so-called photon gases, such as in Bose condensation of light or in attempts to make photonic quantum simulators, suggest one re-examine near-equilibrium cases. Here we consider peculiar driven open quantum system scenarios where near-equilibrium dynamics can lead to equilibration of photons with a finite number, following a thermal description closer to that of an ideal gas than to blackbody radiation. Specifically, we show how laser cooling of a well-isolated mechanical mode or atomic motion can provide an effective bath which enables control of both the chemical potential and the temperature of light. We then theoretically demonstrate that Bose condensation of photons can be realized by cooling an ensemble of two-level atoms inside a cavity. This engineered chemical potential for light admits future applications in many-body quantum simulations and enables an analogous voltage bias for photonic circuit elements.