Reducing Microwave Thermal Noises by Quantum Refrigerators

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Reducing the thermal noises in microwave (MW) resonators can bring about significant progress in many research fields. In this study, we consider using three-level or four-level systems as "quantum refrigerators" to cool down MW resonators so as to reduce the thermal noises, and investigate their possible cooling limits. In such a quantum refrigerator system, the MW resonator is coupled with many three-level or four-level systems. Proper light pump makes the multilevel systems concentrated into their ground states, which continuously absorb the thermal photons in the MW resonator. By adiabatic elimination, we give a more precise description for this cooling process. For three level systems, though the laser driving can cool down the multilevel systems efficiently, a too strong driving strength also significantly perturbs their energy levels, causing the atom-resonator interaction to become off-resonant, which weakens the cooling effect, and that sets a finite region for cooling parameters. In four level systems, by adopting an indirect pumping approach, such a finite cooling region can be further released. In both cases, we obtain analytical results for the cooling limit of the MW resonator. Based on practical parameters, our estimation shows the cooling limit could reach lower than the liquid helium temperature, without resorting to the traditional cryogenic systems.

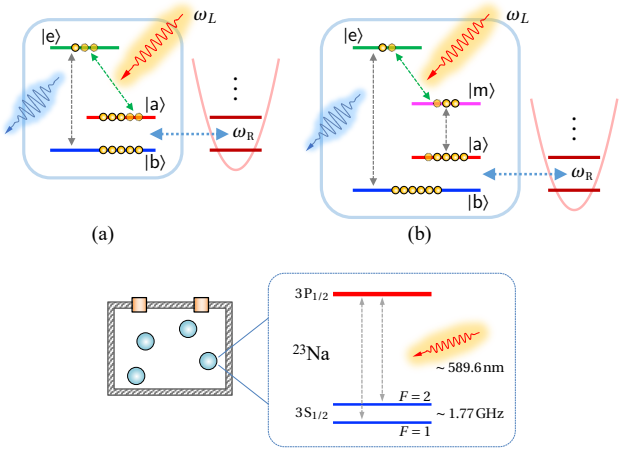

Figure 1: Demonstration for transition structures of the quantum refrigerators

References

[1] H-J Bi and S-W Li, arXiv:2502.08067 (2025)