Abstract of my thesis Violating the thermodynamic uncertainty relation in the three-level laser driven by a thermal bath and an external field

Heat engines have been of interest since the industrialization period. The concept involves converting thermal energy into kinetic energy, which can then be utilized. The concept of converting thermal energy was adopted from (Scovil and Schulz) and applied to a 3-level quantum system. However, in this case, the energy output is a state of light wave. In other words, it is possible to build a maser that is driven by the interaction with a hot and cold reservoir. This study analyzed a modified form of such a three-level maser. The modification compared to the original version is that this three-level system is placed in a cavity and can be driven by an external field. To gain as much knowledge as possible about this quantum heat engine, various aspects are discussed in this thesis. It should be noted that the calculations were performed both analytically using the equations of motion and numerically. One focus was on analyzing the heat flow and its behavior when parameters change. This revealed phenomena that can only be explained quantum mechanically, such as the double-threshold behavior which is described in the paper:Quantum statistics of a single-atom Scovil-Schulz-DuBois heat engine".

The question that arises and we investigate is how the external field affects the system and changes the photocurrent and power. We also investigated the non-linear behavior of the expected value of the latter operator and compared it to the analytical solution outlined in "Giant optical nonlinearity induced by a single two-level system interacting with a cavity in the Purcell regime".

To further understand the heat flow or heat current, we also discuss the thermodynamic uncertainty relation (TUR), as in the current fluctuations in open quantum systems: Bridging the gap between quantum continuous measurements and full counting statistics. We examine thermodynamic uncertainty in detail in the three-level maser and find coherence-induced TUR violations. TUR violation allows us to identify operating regimes where quantum dynamics lead to improved performance quantified by a lower value of the TUR as the classical limit. Interestingly, such a quantum advantage cannot be expected from the off-diagonal elements of the density matrix alone, as fluctuations are not solely encoded in the steady-state coherence. We investigated all the parameters that describe our 3-level maser and found an optimum where TUR violation exists. Our three-level system is also coupled to a hot and cold bath. Additionally, it is driven by an external field. In comparison to the work mentioned before, the three-level system is situated within a cavity. This results in a complete transformation of the state of light, as well as a change in the circumstances under which the thermodynamic imbalance relation (TUR) is violated.