Abstract

Quantum heat engine is a counterpart to the classical thermodynamical heat engine whose working substance or heat bath is of quantum nature. Since the quantum heat engine works in the framework of quantum mechanics, not in that of classical thermodynamics, one may expect that its thermal efficiency can be higher than the upper limit of the classical counterparts. For example, when we construct a quantum analog of the Carnot cycle, we expect that its thermal efficiency could be higher than the classical Carnot efficiency. Motivated by these expectations, both theoretical and experimental studies on several types of quantum heat engines have been conducted. In such attempts, the thermal efficiency higher than the Otto efficiency has been reported for an Otto-like quantum heat engine. In this experiment on the Otto-like cycle, a bath with a negative effective temperature was used. The authors claim that the negative effective temperature is a possible origin of the high efficiency. Since the negative temperatures are often considered as ultra-high temperatures, it seems that the high efficiency is the consequence of the large temperature differences between a heat bath at effectively negative temperatures and another heat bath. However, it has not yet been clear whether the negative effective temperatures are necessary or not to achieve high efficiency. Thus, it is worth studying an quantum heat engine where the effective temperature of the two heat baths is negative.

In this thesis, we theoretically study a quantum heat engine whose working substance is a general two-level system, with focusing on a cycle with quenching dynamics. The two-level system is relevant to the previous experiments and easy to analyse the relation between the efficiency and negative temperature. One may expect that the usage of the two negative temperature heat baths gives lower efficiency since the difference in the temperatures between these heat baths is effectively smaller than the temperature difference between positive and negative temperature heat baths. However, we achieve higher efficiency with two negative temperature heat baths in our theoretical calculation. Moreover, we find a condition to design engines whose efficiency is 1. These analyses give a guide to designing quantum heat engines that

exploit quantum nature of the working substance and show higher efficiency than the classical heat engines.