論文の内容の要旨

論文題目: Design principles in the stochastic thermodynamics of molecular motors
（微小熱力学系としての生体分子モーター設計原理）

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This thesis is dedicated to the theoretical studies on bio-molecular motors, which are fascinating well-designed protein nanomachines that work in various physiological systems. Recent progresses in experimental techniques have led to the measurement of precise physical properties of molecular motors, such as the heat dissipation of rotary motors and the precise aspect of cooperativity in linear cytoplasmic motors. In parallel, there has been considerable advance in the understanding of stochastic thermodynamics, where the behavior of thermodynamic machines in the fluctuating world is the main target of study. In light of these developments, both in experiments and theory, we are now in position to elucidate the fundamental design principles hidden behind the molecular motors.

Two phenomenological models are discussed in this thesis. First is the model for F1-ATPase, which is a rotary motor with outstanding properties in its thermodynamic efficiency. We focus on the recent experimental result on the heat dissipative feature of F1, showing that the dissipation inside the motor is close to zero, irrespective of the velocity of rotation. We arrive at a model with totally asymmetric rules in the rotational angular dependence on the chemical reaction, and find significant consistency with this model to other experimental data such as the characteristic torque-velocity curve of F1. Through the model, we give predictions on the physics of the reverse rotation of F1, where ATP synthetic reactions occur.

Secondly, we consider a model for cytoplasmic molecular motors, which are proteins that transport cargoes along pseudo-one-dimensional rails called cytoskeletons. Experiments have clarified the large dependence of the transport velocity on the number of tied molecular motors such as myosins and dyneins. In our model, we take into account the typical two states of molecular motor heads, the highly diffusive state and the strongly bound state, and consider the stochastic switching between them through a force-sensor controlled rule. The scheme allows diffusive and bidirectional elements to produce unidirectional transport through collective interaction. We analyze how the sensitivity of the force-sensor affects the cooperativity of the motors, defined by the ratio between the velocity with two molecules and infinitely many molecules. We discuss on the possibility to classify the various cytoplasmic motors through the phase diagram obtained in our simple model.