A Modern Introduction to Nonequilibrium Statistical Mechanics

Hal Tasaki

online lecture, summer 2023

about the present lecture 1

a self-contained introduction to nonequilibrium statistical mechanics for graduate (and motivated undergraduate) students (mainly) in physics

based on my graduate courses in 2021 and 2023 at Gakushuuin

novel approach based on modern (and hopefully clear) points of view

starts from the Jarzynski equality and the fluctuation theorem

ends with Einstein's theory of Brownian motion

about the present lecture 2

places main emphasis on general results and concepts, rather than practical applications

we mainly study Markov jump processes (Markov processes with discrete states and continuous time)

covers standard results such as linear response relations and the reciprocal relation and modern results such as the fluctuation theorem and the Jarzynski equality

mostly mathematically rigorous, but only uses elementary undergraduate mathematics

prerequisite

basic abstract math languages, elementary calculus including differentiation and integration, elementary linear algebra (vectors and matrices)

we don't assume advanced knowledge in the probability theory

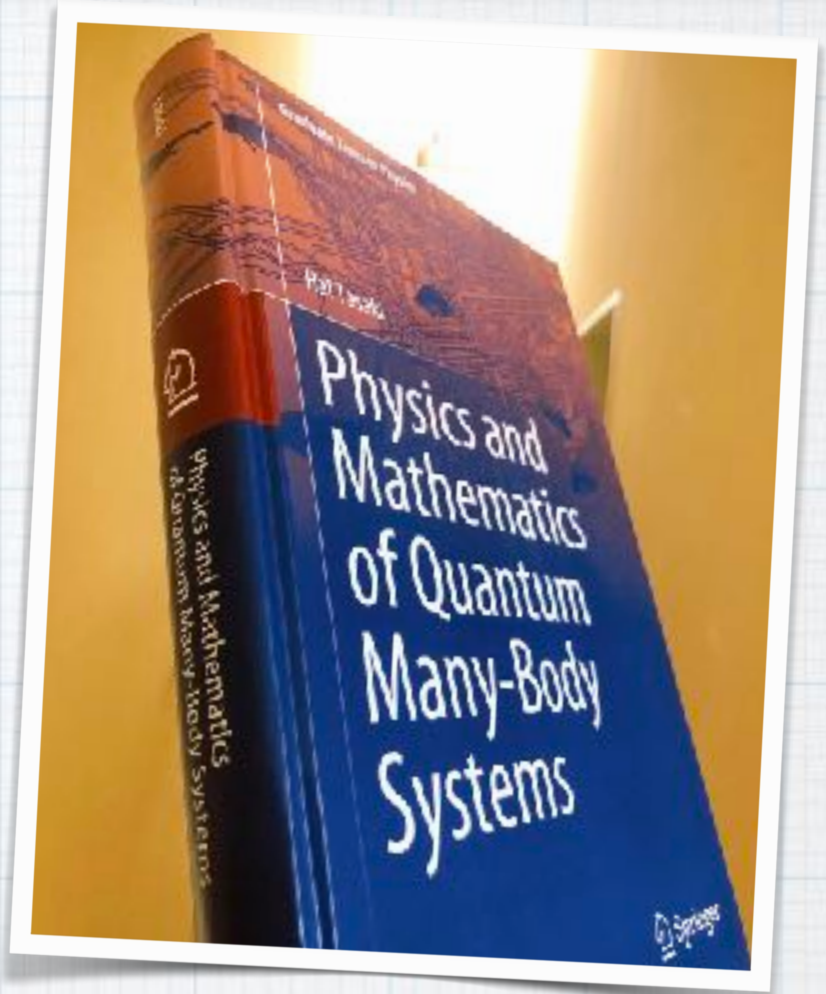
basics of classical mechanics, some working knowledge on classical statistical mechanics

no quantum physics

we try to carefully introduce necessary concepts in part 2

about the lecturer

Hal Tasaki is a mathematical physicist who did some works on quantum many-body systems



he has also been interested in and fascinated by nonequilibibirium statistical mechanics...

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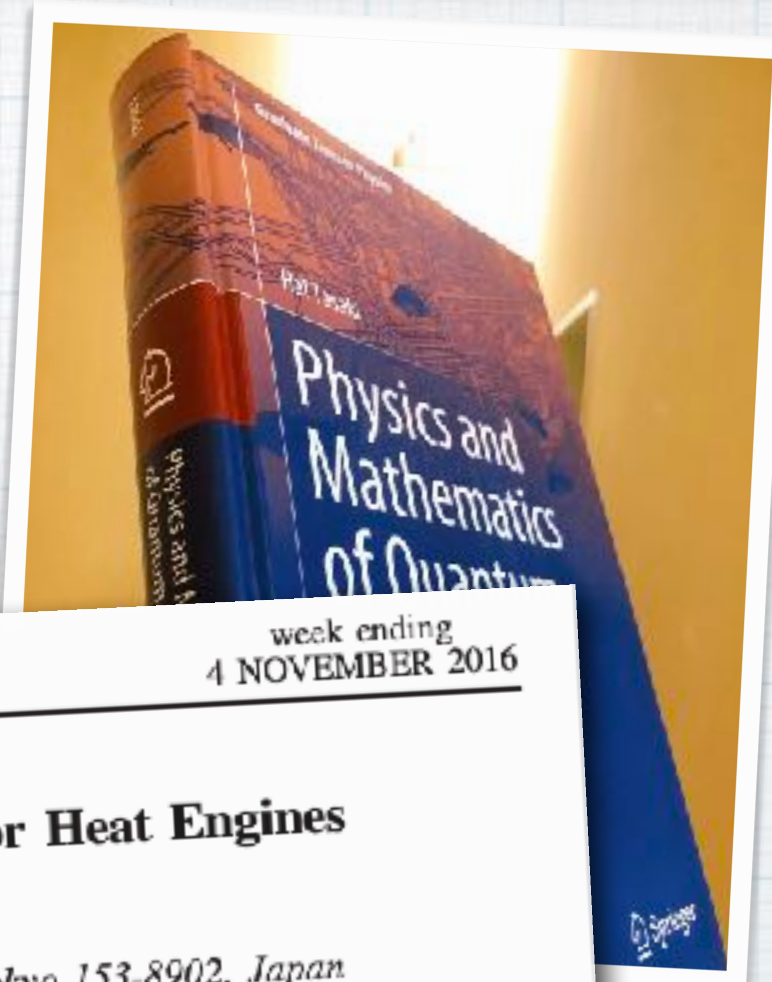

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Universal Trade-Off Relation between Power and Efficiency for Heat Engines

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For a general thermodynamic system described as a Markov process, we prove a general lower bound for dissipation in terms of the square of the heat current, thus establishing that nonvanishing current inevitably implies dissipation. This leads to a universal trade-off relation between efficiency and power, with which we rigorously prove that a heat engine with nonvanishing power never attains the Carnot efficiency. Our theory applies to systems arbitrarily far from equilibrium, and does not assume any specific symmetry of the model.

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Heat engines have been among central topics of thermodynamics since the seminal work of Carnot [1,2], who established that the efficiency of any heat engine operating

This observation triggered a number of studies on the relation between power and efficiency [15–26,29–33].

Studies based on concrete models mainly within the linear response regime [15–28] have denied the possibility

general references

K. Sekimoto, “Stochastic Energetics” (Lecture Notes in Physics 799, Springer 2010)

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N. Shiraishi, “An Introduction to Stochastic Thermodynamics: From Basic to Advanced”, (Springer, Fundamental Theories of Physics 212, 2023)

H. Tasaki “A Modern Introduction to Nonequilibrium Statistical Mechanics”, ???