Contents

Preface ix

Acknowledgments xiii

Author biographies xv

1 The principles of modern thermodynamics 1-1

1.1 A phenomenological theory of heat and work 1-1

1.1.1 The five laws of thermodynamics 1-2

1.1.2 Finite-time thermodynamics and endoreversibility 1-8

1.2 The advent of Stochastic Thermodynamics 1-10

1.2.1 Microscopic dynamics 1-11

1.2.2 Stochastic energetics 1-13

1.2.3 Jarzynski equality and Crooks theorem 1-14

1.3 Foundations of statistical physics from quantum entanglement 1-18

1.3.1 Entanglement assisted invariance 1-19

1.3.2 Microcanonical state from envariance 1-19

1.3.3 Canonical state from quantum envariance 1-21

1.4 Work, heat, and entropy production 1-24

1.4.1 Quantum work and quantum heat 1-24

1.4.2 Quantum entropy production 1-27

1.4.3 Two-time energy measurement approach 1-28

1.4.4 Quantum fluctuation theorem for arbitrary observables 1-33

1.4.5 Quantum entropy production in phase space 1-35

1.5 Checklist for 'The principles of modern thermodynamics' 1-37

1.6 Problems 1-37

References 1-38

2 Thermodynamics of quantum systems 2-1

2.1 Quantum thermometry 2-1

2.1.1 Thermometry for harmonic spectra 2-3

2.1.2 Optimal thermometers 2-5

2.2 Quantum heat engines—engines with atomic working fluids 2-6

2.2.1 The Otto cycle: classical to quantum formulation 2-6

2.2.2 A two-level Otto cycle 2-8

2.2.3 Endoreversible Otto cycle 2-12

2.3 Work extraction from quantum systems 2-18
2.3.1 Work extraction from arrays of quantum batteries 2-19
2.3.2 Powerful charging of quantum batteries 2-23
2.4 Quantum decoherence and the tale of quantum Darwinism 2-24
2.4.1 Work, heat, and entropy production for dynamical semigroups 2-24
2.4.2 Entropy production as correlation 2-27
2.4.3 Quantum Darwinism: emergence of classical objectivity 2-29
2.5 Checklist for 'Thermodynamics of quantum systems' 2-33
2.6 Problems 2-33
References 2-35

3 Thermodynamics of quantum information 3-1

3.1 Quantum thermodynamics of information 3-2
3.1.1 Thermodynamics of classical information processing 3-2
3.1.2 A quantum sharpening of Landauer's bound 3-6
3.1.3 New Landauer bounds for nonequilibrium quantum systems 3-8
3.2 Performance diagnostics of quantum annealers 3-10
3.2.1 Fluctuation theorem for quantum annealers 3-11
3.2.2 Experimental test on the D-Wave machine 3-13
3.3 Kibble–Zurek scaling of irreversible entropy 3-14
3.3.1 Fundamentals of the Kibble–Zurek mechanism 3-16
3.3.2 Example: the Landau–Zener model 3-17
3.3.3 Kibble–Zurek mechanism and entropy production 3-18
3.4 Error correction in adiabatic quantum computers 3-21
3.4.1 Quantum error correction in quantum annealers 3-22
3.4.2 Adiabatic quantum computing—a case for shortcuts to adiabaticity 3-23
3.4.3 Counterdiabatic Hamiltonian for scale-invariant driving 3-25
3.5 Checklist for 'Thermodynamics of quantum information' 3-31
3.6 Problems 3-31
References 3-33

Epilogue 4-1