Contents

1 Thermodynamics as a Universal Science 1
1.1 Transmission of thermal power 1
Accumulation equation 3
1.2 Examples of oneport-C's and multiport-C's 4
Oneports 4
Twoports and multiports 5
Mechanical example of a table with leg fixed to the ground . . . 5
Moving plates capacitor as an electromechanical example 6
1.3 Thermal multiport-C and the laws of thermodynamics 8
1.3.1 General 8
1.3.2 Control engineering block diagrams 9
1.3.3 Entropy after Clausius 11
1.3.4 Principles or laws of thermodynamics 12
1.4 Thermodynamics in pictures 13
1.5 Case of an ideal gas 15
1.6 Equilibrium in thermodynamics and electricity 16
1.7 Thermal radiation 18

2 Frictions and Irreversibilities 23
2.1 Frictions of all kinds 23
2.2 Heat conduction over a finite temperature drop, and combined conduction 24
Combined entropy and electric conduction 26
2.3 Carnot cycle between two sources with friction 28
2.4 Heat flux and entropy flow 31

3 Mass Flows ... 33
3.1 Flow processes ... 33
3.2 Enthalpy and entropy in fluids pipes ... 39
3.3 Heat exchangers ... 41
3.4 Thermal turbo machines ... 42
3.5 Gas flow between two vessels with scavenging ... 44
3.6 Two-phase flow in boilers and condensers ... 47
3.7 Units and overvalues in thermodynamics ... 50
Origins of entropy and enthalpy ... 51
3.8 Exergy, an accountant's reserve ... 51
3.9 High velocity turbomachines ... 52

4 Chemical Reactions and Osmosis ... 57
4.1 Chemical equilibria and entropy stripping ... 57
Entropy Stripping ... 60
4.2 Chemical reactions ... 66
4.3 Near to and far from equilibrium ... 69
4.4 Parallel and competing reactions ... 70
4.5 Osmosis as a bridge between physical, chemical and biological effects ... 70
4.6 Reversible mixing and Gibb's paradox ... 74
4.7 Tellegen's theorem and chemical inductance ... 77
Tellegen's theorem: ... 77
Chemical inductance ... 78

5 Entropy and Information Theory ... 79
5.1 Orders of magnitude and microscopic entropy ... 79
5.2 Entropy of a message after Shannon ... 80
5.3 Micro-information and negentropy ... 82
5.4 Information theory, noise and organization ... 83
5.5 Applications ... 84
5.5.1 Brusselator and Prigogine's minimum entropy principle 84
5.5.2 Bhopalator ... 87
5.5.3 Information theory, diesel locomotives and capital ... 88
Energy Consumption ... 89
Transmission of Technical Information ... 89
5.5.4 Solar energy and thermal balance of the earth ... 90
Climate Change and Global Warming ... 92
Negentropic city ... 93
5.5.5 Philosophical questions ... 93

Bibliography ... 95

Appendix 1 Understanding with Bond Graphs 101
A1.1 Elements 101
A1.1.1 Bonds and connections 102
A1.1.2 One port elements or one ports 103
A1.1.3 One and a half ports 104
A1.1.4 Two port elements or two ports 104
A1.1.5 Junctions elements or three ports 105
A1.1.6 Multiport elements or multiports 106
A1.2 Energy and power conservation 107
A1.3 Power signs 108
A1.4 Negative resistances and negative C-elements 110
A1.5 Compact units in pneumatics and hot gas 110
A1.6 Multiport-C signs in thermodynamics and Maxwell relations . . 112

Appendix 2 Control Systems with Bond Graphs 115

Appendix 3 Historical Notes 119

Epilogue 121

Concepts 123

Symbols 129

Index 135