

---

## Contents

---

<b>Preface .....</b>	xii
<b>Introduction .....</b>	xiii
<b>Chapter 1. Form and Matter: The Genesis of Materials .....</b>	1
1.1. Role and evolution of geometric shapes in chemistry .....	2
1.1.1. Shape and matter: the origins .....	2
1.1.2. From the Renaissance to modern chemistry .....	4
1.1.3. Modern era .....	6
1.2. Contributions of complexity of forms and thermodynamics .....	9
1.2.1. Development of more complex forms .....	9
1.2.2. Introduction to generalized thermodynamics .....	11
1.2.3. Toward a classification of materials .....	13
1.3. Perspectives .....	14
<b>Chapter 2. Thermodynamics of Condensed Matter .....</b>	15
2.1. Definitions in thermodynamics .....	16
2.1.1. Concept of a thermodynamic system .....	16
2.1.2. Review of thermodynamic equilibrium states .....	17
2.1.3. Energy transformations and efficiency .....	20
2.1.4. Systems without thermodynamic equilibrium .....	23
2.2. Examples of hardware systems .....	26
2.2.1. Responses close to equilibrium .....	27
2.2.2. Responses far from equilibrium .....	29
2.2.3. Role of chemical reactors .....	33
2.3. Material development and characterization .....	36
2.3.1. Situation close to equilibrium: crystallogenesis .....	36
2.3.2. Situation far from equilibrium: morphogenesis .....	40

2.3.3. Production processes . . . . .	43
2.4. Conclusion . . . . .	43
<b>Chapter 3. Classification of Materials</b> . . . . .	45
3.1. Role of surfaces and interfaces . . . . .	46
3.1.1. Nature and symmetry of a phase separation . . . . .	46
3.1.2. Classification according to the requirements . . . . .	47
3.1.3. Composition of a system . . . . .	47
3.1.4. Type of responses and functionality . . . . .	49
3.2. Main types of materials and systems . . . . .	50
3.2.1. Structural materials . . . . .	50
3.2.2. Electronic operators and transmitters . . . . .	53
3.2.3. Optical devices . . . . .	58
3.2.4. Adsorbers and chemical sensors . . . . .	64
3.2.5. Actuators and their analogues . . . . .	69
3.3. Conclusion . . . . .	69
<b>Chapter 4. Materials and Devices for Energy and Information</b> . . . . .	71
4.1. Conversion and storage of electrical energy . . . . .	71
4.1.1. Direct conversion electric generators . . . . .	72
4.1.2. Indirect production and use of electricity . . . . .	80
4.1.3. Storage of energy . . . . .	83
4.2. Recording and storing information . . . . .	85
4.2.1. Main features . . . . .	86
4.2.2. Main types of memories . . . . .	87
4.3. Conclusion . . . . .	92
<b>Chapter 5. Microscopic Models and Statistical Thermodynamics</b> . . . . .	95
5.1. Typical microscopic models . . . . .	95
5.1.1. Law of distribution and definition of statistical entropy . . . . .	96
5.1.2. Thermodynamic systems and canonical ensembles . . . . .	97
5.1.3. Situations beyond equilibrium . . . . .	98
5.1.4. Stochastic thermodynamics . . . . .	100
5.2. Quantum statistics . . . . .	101
5.2.1. Review of concepts . . . . .	101
5.2.2. Quantum distribution laws . . . . .	101
5.2.3. Elementary excitations and quantum particles in solids . . . . .	103
5.3. Information theory . . . . .	105
5.3.1. Shannon–Brillouin model . . . . .	105
5.3.2. Energy and information: the Landauer principle . . . . .	106

---

5.3.3. The role of quantum mechanics . . . . .	108
5.3.4. Remarks on the notion of information and the concept of entropy . . . . .	110
5.4. Conclusion . . . . .	112
<b>Chapter 6. Nanomaterials</b> . . . . .	113
6.1. The new classes of materials. . . . .	113
6.1.1. Conjugate conductive polymers . . . . .	114
6.1.2. Charge transfer salts and complexes. . . . .	115
6.1.3. Molecular carbonaceous phases . . . . .	116
6.1.4. Other nanomaterials . . . . .	118
6.2. Nanometric assemblies and manipulations . . . . .	118
6.2.1. Thin film techniques and imposed structures . . . . .	119
6.2.2. Supramolecular chemistry and the colloidal approach . . . . .	120
6.2.3. Nanowires and nanocomposites . . . . .	123
6.2.4. Detection and manipulation of particles. . . . .	124
6.2.5. Molecular recognition, nanosensors and actuators . . . . .	126
6.3. Conclusion . . . . .	128
<b>Chapter 7. Engineering and Molecular Electronics</b> . . . . .	129
7.1. Nanotechnologies . . . . .	129
7.1.1. Nanoelectronics . . . . .	129
7.1.2. Nanophotonics . . . . .	133
7.1.3. Nanomagnetism. . . . .	138
7.1.4. Nanomachines. . . . .	141
7.2. Memory and quantum logic . . . . .	143
7.2.1. Quantum phenomena. . . . .	143
7.2.2. Experimental devices . . . . .	144
7.2.3. Information, thermodynamics and quantum chaos . . . . .	147
7.3. State of the art: nanomaterials and quantum electronics . . . . .	148
<b>Chapter 8. Living World, Biomaterials and Biosystems</b> . . . . .	149
8.1. Living systems and energy balances . . . . .	150
8.1.1. On the definition of the living world . . . . .	150
8.1.2. Thermodynamic model . . . . .	152
8.1.3. Conversion and storage of energy . . . . .	154
8.1.4. Operation of a cell reactor. . . . .	158
8.2. Biomaterials and biosystems. . . . .	158
8.2.1. Morphogenesis and biomimicry . . . . .	159
8.2.2. Biodetectors and similar functions. . . . .	162
8.2.3. Bioconverters and natural energy sources . . . . .	165

---

8.2.4. Engines, receptors and bionic robots . . . . .	170
8.2.5. Bioinformatics . . . . .	171
8.2.6. Biosynthesis . . . . .	174
8.3. Conclusion . . . . .	175
<b>Chapter 9. Extensions to Living Organisms and Ecology . . . . .</b>	<b>177</b>
9.1. Behavior of cells and organs . . . . .	178
9.1.1. Biochemical oscillations and biological rhythms . . . . .	178
9.1.2. Spatiotemporal organizations and Turing structures . . . . .	180
9.1.3. Rhythms and chaos in certain organs . . . . .	182
9.1.4. Neural networks, information and cognitive behavior . . . . .	183
9.2. Physiology of a living organism . . . . .	187
9.2.1. Thermodynamic system and metabolism . . . . .	187
9.2.2. Collective behavior . . . . .	189
9.3. Ecosystems and natural cycles . . . . .	190
9.3.1. The predator–prey relationship . . . . .	191
9.3.2. Grand natural cycles . . . . .	193
9.3.3. Climate models . . . . .	194
9.4. Conclusion . . . . .	196
<b>Chapter 10. Application of Thermodynamics to Economy . . . . .</b>	<b>199</b>
10.1. Thermodynamic models of economy . . . . .	200
10.1.1. Chronology of energy models . . . . .	200
10.1.2. Analysis of fundamental concepts . . . . .	205
10.2. Dynamics of economic and financial systems . . . . .	209
10.2.1. Economic cycles . . . . .	209
10.2.2. Analysis of financial fluctuations . . . . .	210
10.2.3. Stock market crashes . . . . .	211
10.2.4. Statistical modeling of financial systems . . . . .	212
10.2.5. On the behavior of a financial system . . . . .	214
10.3. Conclusion . . . . .	215
<b>Chapter 11. From Thermodynamic Systems to Complex Systems . . . . .</b>	<b>217</b>
11.1. Thermodynamic models: from energy to entropy . . . . .	218
11.1.1. Modeling of a thermodynamic system . . . . .	218
11.1.2. Entropy and information . . . . .	221
11.2. Classification of materials and devices . . . . .	224
11.2.1. Functional advanced materials . . . . .	224
11.2.2. Nanomaterials and quantum mechanics . . . . .	225
11.2.3. Biomaterials inspired by living environments . . . . .	226

11.2.4. Extension to living organisms, ecological and economic systems . . . . .	227
11.3. Rhythms, complexity and synergy of dynamic systems . . . . .	228
11.3.1. From the analysis of shape to functionality . . . . .	228
11.3.2. Scale analysis and organizational hierarchy . . . . .	229
11.3.3. Constraints and flows: characteristic oscillations and cycles . . . . .	230
11.3.4. Dynamic and cybernetic systems . . . . .	231
11.3.5. Toward a definition of complex systems . . . . .	233
11.4. Epilogue: descriptive uniqueness and limitation of thermodynamic bases . . . . .	235
<b>Glossary</b> . . . . .	237
<b>Bibliography</b> . . . . .	243
<b>Index</b> . . . . .	267