

Contents

	<i>Preface</i>	<i>page ix</i>
1	Thermodynamic entropy	1
1.1	Thermodynamics and entropy	1
1.2	Reversible and irreversible processes	2
1.3	The second law of thermodynamics	5
1.4	Entropy and irreversibility	7
1.5	Quantifying irreversibility	9
1.6	The Carnot efficiency and Carnot's theorem	13
1.7	Absolute or thermodynamic temperature	15
1.8	Consequences of the second law	18
1.9	Equations of state	21
1.10	The third law of thermodynamics	27
	Problems	28
2	Statistical entropy	32
2.1	Boltzmann and atoms	32
2.2	Microstates and macrostates	33
2.3	Fundamental postulate	36
2.4	Statistical entropy and multiplicity	39
2.5	Maxwell's demon	47
2.6	Relative versus absolute entropy	49
	Problems	50
3	Entropy of classical systems	53
3.1	Ideal gas: volume dependence	53
3.2	Ideal gas: volume and energy dependence	54
3.3	Imposing extensivity	58
3.4	Occupation numbers	60

3.5	Ideal classical gas	66
3.6	Ideal classical solid	67
3.7	Boltzmann's tomb	71
	Problems	73
4	Entropy of quantized systems	75
4.1	Quantum conditions	75
4.2	Quantized harmonic oscillators	76
4.3	Einstein solid	81
4.4	Phonons	82
4.5	Third law	85
4.6	Paramagnetism	88
4.7	Negative absolute temperature	90
	Problems	93
5	Entropy of a non-isolated system	96
5.1	Beyond the fundamental postulate	96
5.2	The Gibbs entropy formula	97
5.3	Canonical ensemble	100
5.4	Partition functions	102
5.5	Entropy metaphors	103
	Problems	104
6	Entropy of fermion systems	105
6.1	Symmetries and wave functions	105
6.2	Intrinsic semiconductors	106
6.3	Ideal Fermi gas	110
6.4	Average energy approximation	118
	Problems	120
7	Entropy of systems of bosons	122
7.1	Photons	122
7.2	Blackbody radiation	123
7.3	Ideal Bose gas	126
7.4	Bose–Einstein condensate	133
7.5	Modeling the ideal gas	136
	Problems	138
8	Entropy of information	140
8.1	Messages and message sources	140
8.2	Hartley's information	141
8.3	Information and entropy	143

8.4	Shannon entropy	145
8.5	Fano code	148
8.6	Data compression and error correction	151
8.7	Missing information and statistical physics	153
	Problems	156
	<i>Epilogue</i>	159
	<i>Appendix I Physical constants and standard definitions</i>	161
	<i>Appendix II Formulary</i>	162
	<i>Appendix III Glossary</i>	163
	<i>Appendix IV Time line</i>	169
	<i>Appendix V Answers to problems</i>	172
	<i>Appendix VI Annotated further reading</i>	175
	<i>Index</i>	178

Actually, scientists have no choice but to understand entropy because the concept describes an important aspect of reality. We know how to calculate and how to measure the entropy of a physical system. We know how to use entropy to solve problems and to place limits on processes. We understand the role of entropy in thermodynamics and in statistical mechanics. We also understand the parallelism between the entropy of physics and chemistry and the entropy of information theory.

But von Neumann's witticism contains a kernel of truth: entropy is difficult, if not impossible, to visualize. Consider that we are able to invest the concept of the energy of a rod of iron with meaning by imagining the rod broken into its smallest parts, atoms of iron, and comparing the energy of an iron atom to that of a macroscopic, massive object attached to a network of springs that model the interactions of the atom with its nearest neighbors. The object's energy is then the sum of its kinetic and potential energies – types of energy that can be studied in elementary physics laboratories. Finally, the energy of the entire system is the sum of the energy of its parts.

These imaginative transitions – first to analyze a whole into its parts, second to compare each part with a familiar object, third to recognize the quantity sought in the familiar object, and finally to recombine the whole out