

Contents

Preface.....	xvii
Acknowledgments.....	xix
Authors.....	xxi

PART I — Thermodynamics

Chapter 1. Systems and their Surroundings.....	3
Questions.....	4
Chapter 2. State Functions and the Laws of Thermodynamics.....	5
2.1 General Considerations: State Variables and State Functions.....	5
2.2 The Internal Energy U and the First Law of Thermodynamics.....	7
2.2.1 Internal Energy, Heat, and Work.....	7
2.2.2 The First Law of Thermodynamics.....	8
2.2.3 The Ideal Gas: A Convenient System to Understand Thermodynamic Principles.....	9
2.2.4 Changes in the State of an Ideal Gas.....	12
2.2.4.1 Irreversible Isothermal Expansion and Compression.....	12
2.2.4.2 Reversible Isothermal Expansion and Compression.....	13
2.2.4.3 Comparison of Reversible and Irreversible Changes of State.....	14
2.2.4.4 Adiabatic Expansion and Compression.....	16
2.2.5 Thermodynamic Cycles: Back and Forth or Round and Round.....	20
2.2.5.1 The Carnot Process.....	21
2.2.6 The Temperature Dependence of the Internal Energy U	25
2.3 The Enthalpy H	26
2.4 The Entropy S and the Second Law of Thermodynamics.....	29
2.4.1 Predicting Spontaneity of Processes: Dissipation of Heat and Matter.....	29
2.4.2 Entropy and Heat.....	30
2.4.3 Temperature Dependence of the Entropy.....	32
2.4.4 The Third Law of Thermodynamics and Absolute Entropy.....	33
2.4.5 Entropy and Order: The Statistic Interpretation.....	34
2.5 The Free Energy G : Combining System and Surroundings.....	37
2.5.1 Entropy- and Enthalpy-Driven Reactions.....	39
2.5.2 Pressure and Temperature Dependence of the Free Energy.....	41

2.5.3	Standard States.....	43
2.5.4	Relation of Free Energy, Enthalpy, and Entropy to Molecular Properties.....	44
2.6	The Chemical Potential μ	46
2.6.1	The Chemical Potential as a Driving Force for Chemical Reactions.....	46
2.6.2	The Chemical Potential and Stable States: Phase Diagrams.....	48
2.6.3	Pressure and Temperature Dependence of the Chemical Potential.....	51
2.6.4	The Chemical Potential as a Partial Molar Property.....	51
2.6.5	The Chemical Potential of Compounds in Mixtures.....	52
2.6.6	The Chemical Potential of Solutions.....	55
2.6.7	Colligative Properties.....	57
	Questions.....	64
	References.....	65
Chapter 3.	Energetics and Chemical Equilibria.....	67
3.1	The Free Energy Change and the Equilibrium Constant.....	67
3.1.1	Temperature Dependence of the Equilibrium Constant.....	69
3.1.2	The Principle of Le Chatelier.....	70
3.2	Binding and Dissociation Equilibria and Affinity.....	71
3.3	Protolysis Equilibria: The Dissociation of Acids and Bases in Water.....	74
3.4	Thermodynamic Cycles, Linked Functions and Apparent Equilibrium Constants.....	75
	Questions.....	82
	References.....	83
Chapter 4.	Thermodynamics of Transport Processes.....	85
4.1	Diffusion.....	85
4.2	The Chemiosmotic Hypothesis.....	90
4.3	Active and Passive Transport.....	92
4.4	Directed Movement by the Brownian Ratchet.....	94
	Questions.....	98
	References.....	98
Chapter 5.	Electrochemistry.....	101
5.1	Redox Reactions and Electrochemical Cells.....	101
5.2	Types of Half-Cells.....	104
5.3	Standard Electrode Potentials.....	105
5.4	The Nernst Equation.....	106
5.5	Measuring pH values.....	108
5.6	Redox Reactions in Biology.....	109
5.6.1	The Respiratory Chain.....	109
5.6.2	The Light Reaction in Photosynthesis.....	110
5.7	The Electrochemical Potential and Membrane Potentials.....	111
5.8	Electrophysiology: Patch-Clamp Methods to Measure Ion Flux through Ion Channels.....	114
	Questions.....	115
	References.....	116
Chapter 6.	Reaction Velocities and Rate Laws.....	119
	Questions.....	123
Chapter 7.	Integrated Rate Laws for Uni- and Bimolecular Reactions.....	125
	Questions.....	135

Chapter 8.	Reaction Types	137
8.1	Reversible Reactions	137
8.2	Parallel Reactions	140
8.3	Consecutive Reactions	142
	Questions	146
	Reference	146
Chapter 9.	Rate-Limiting Steps	147
	Questions	151
	References	151
Chapter 10.	Binding Reactions: One-Step and Two-Step Binding	153
	Questions	159
	References	159
Chapter 11.	Steady-State (Enzyme) Kinetics	161
11.1	Rapid Equilibrium (Michaelis-Menten Formalism)	162
11.2	Steady-State Approximation (Briggs-Haldane Formalism)	164
11.3	pH Dependence	167
11.4	Two or More Non-Interacting Active Sites	172
11.5	Two or More Interacting Active Sites: Cooperativity and the Hill Equation	175
11.6	Inhibition of Enzyme Activity	179
11.6.1	Product Inhibition in Reversible Reactions	179
11.6.2	Competitive Inhibition	182
11.6.3	Non-Competitive Inhibition	183
11.6.4	Mixed Inhibition	185
	Questions	187
	References	189
Chapter 12.	Complex Reaction Schemes and their Analysis	191
12.1	Binding of Two Substrates	191
12.1.1	Random Binding	191
12.1.2	Ordered Binding	193
12.2	Ping-Pong Mechanism	196
12.3	Net Rate Constants and Transit Times	197
	Questions	200
	References	200
Chapter 13.	Temperature Dependence of Rate Constants	203
13.1	The Arrhenius Equation	203
13.2	Transition State Theory	203
13.3	Collision Theory	206
13.4	Kinetic and Thermodynamic Control of Reactions	207
	Questions	208
Chapter 14.	Principles of Catalysis	209
14.1	Enzyme Catalysis	209
14.2	Acid-Base Catalysis	211
14.3	Electrostatic and Covalent Catalysis	215
14.4	Intramolecular Catalysis and Effective Concentrations	216
	Questions	216
	References	217

Chapter 15. Molecular Structure and Interactions	221
15.1 Configuration and Conformation	221
15.2 Covalent Interactions	224
15.2.1 Covalent Bonds.....	225
15.2.2 Bond Angles and Torsion Angles.....	225
15.3 Non-Covalent Interactions	227
15.3.1 Ionic Interactions	229
15.3.2 Interactions between Ions and Dipoles.....	229
15.3.3 Hydrogen Bonds	232
15.3.4 Interactions between Induced Dipoles: van der Waals Interactions	234
Questions	237
References	237
Chapter 16. Proteins	239
16.1 Amino Acids and the Peptide Bond	239
16.1.1 Properties of the Twenty Canonical Amino Acids.....	239
16.1.2 The Peptide Bond	241
16.1.3 Side-Chain Rotamers.....	243
16.1.4 Post-Translational Modifications	244
16.1.4.1 Glycosylation	245
16.1.4.2 Phosphorylation	245
16.1.4.3 Hydroxylation.....	246
16.1.4.4 Carboxylation.....	247
16.1.4.5 Disulfide Bonds	248
16.1.4.6 Metal Binding.....	248
16.2 Protein Structure	251
16.2.1 Helical Secondary Structure Elements	253
16.2.1.1 α -helix.....	253
16.2.1.2 3_{10} , poly-Pro, and Collagen Helices	255
16.2.2 β -Strands and their Super-Secondary Structures (β -Sheets).....	257
16.2.3 Reverse Turns	260
16.2.4 Protein Domains & Tertiary Structure	262
16.2.5 Quaternary Structure & Protein-Protein Interactions	265
16.2.5.1 Homo-Oligomers	265
16.2.5.2 Hetero-Oligomers.....	267
16.2.6 Protein-Protein Interactions.....	268
16.2.6.1 Surface Complementarity and Buried Surface Area.....	268
16.2.6.2 Energetics of Macromolecular Interactions	269
16.2.6.3 Role of Water – The Hydrophobic Effect.....	269
16.2.7 Protein-Ligand Interactions.....	271
16.2.8 Membrane Proteins and their Lipid Environment.....	273
16.2.8.1 Biological Roles of Lipids and Membranes.....	273
16.2.8.2 Types of Lipids	275
16.2.8.3 Super-Structures Formed by Lipids and Detergents	275
16.2.8.4 Properties and Structure of Membrane Proteins	277
16.3 Folding and Stability.....	279
16.3.1 Driving Forces for Protein Folding.....	280
16.3.2 First Folding Experiments and the Levinthal Paradox	282

16.3.3	Energy Landscapes for Protein Folding	283
16.3.4	Mathematical Description of the Two-State Model	285
16.3.5	Folding Pathways and Mechanisms of Protein Folding	290
16.3.5.1	Fast Steps in Protein Folding: Secondary Structure Formation	292
16.3.5.2	Rate-Limiting Steps and Protein Folding <i>In Vivo</i>	293
16.3.5.3	Kinetics of Protein Folding	295
16.3.5.4	Folding Intermediates in Monomers and Oligomers	296
16.3.6	Protein Folding Diseases	297
	Questions	299
	References	300
	Online Resources	302
Chapter 17.	Nucleic Acids	303
17.1	Nucleobases, Nucleosides and Nucleotides	304
17.1.1	Non-Standard Nucleobases in DNA	305
17.1.2	Non-Standard Nucleobases in RNA	306
17.2	Ribose and Nucleobase Conformations	307
17.2.1	Sugar Pucker	307
17.2.2	<i>Syn</i> - and <i>Anti</i> -Conformations	308
17.3	Primary Structure of Nucleic Acids	309
17.4	Base Pairing and Stacking	311
17.4.1	H-bonds between Nucleobases	311
17.4.2	Importance of Base Pair Stacking for Double Helix Formation	313
17.4.3	Base Pair Geometries	314
17.5	DNA Structures and Conformations	315
17.5.1	DNA Double Helical Structures	315
17.5.2	Triple and Quadruple DNA Helices	318
17.5.2.1	Triplexes	318
17.5.2.2	Quadruplexes and Telomeres	319
17.5.3	Higher Order DNA Structures	320
17.5.3.1	Helix Junctions	320
17.5.3.2	DNA Supercoiling	322
17.5.3.3	DNA Bending and Kinking	328
17.5.4	DNA Interactions with Proteins and Ligands	329
17.5.4.1	DNA Recognition by Proteins	329
17.5.4.2	Small Molecule Binding to DNA	333
17.6	RNA Structure	334
17.6.1	RNA Secondary Structure	335
17.6.2	RNA Tertiary Structure	336
17.6.3	RNA Folding	338
	Questions	338
	References	339
	Online Resources	340
Chapter 18.	Computational Biology	341
18.1	Sequence Analysis	341
18.1.1	Sequence Composition, Global Properties, and Motifs	341
18.1.1.1	DNA Sequences	342
18.1.1.2	RNA Secondary Structure Prediction	342
18.1.1.3	Protein Sequence Composition and Properties	343
18.1.2	Sequence Alignment	345
18.1.3	Secondary Structure Prediction	348

18.2	Molecular Modeling	348
18.2.1	Force Fields	349
18.2.2	Energy Minimization	350
18.2.3	Molecular Mechanics and Dynamics	352
18.2.3.1	Boundary Conditions and Solvation	353
18.2.3.2	Integration of the Newtonian Equations	354
18.2.3.3	Trajectory Analysis	355
18.2.4	Applications of Molecular Modeling to Macromolecules	356
18.2.4.1	Fold Recognition	357
18.2.4.2	Homology Modeling	358
18.2.4.3	Simulated Annealing	358
18.2.4.4	Coarse-Grained Modeling	359
	Questions	359
	References	360
	Online resources	360

PART IV — Methods

Chapter 19.	Optical Spectroscopy	365
19.1	Interaction of Light and Matter	365
19.1.1	Light as an Electromagnetic Wave	365
19.1.2	Principles of Spectroscopy: Transitions in Two-State Systems	367
19.2	Absorption	369
19.2.1	Electronic, Vibronic, and Rotational Energy Levels	369
19.2.2	Transitions and Transition Dipoles	370
19.2.3	The Lambert-Beer Law	372
19.2.4	Solvent Effects and Influence of the Local Environment	374
19.2.5	Instrumentation	375
19.2.6	Biological Chromophores	375
19.2.7	Applications	380
19.2.7.1	Concentration Determination	380
19.2.7.2	Spectroscopic Assays for Enzymatic Activity	381
19.2.7.3	Spectroscopic Tests for Functional Groups	383
19.2.7.4	Absorption as a Probe for Structural Changes	384
19.2.8	Potential Pitfalls	386
19.3	Linear and Circular Dichroism	387
19.3.1	Linearly Polarized Light and Linear Dichroism	387
19.3.2	Circularly Polarized Light and Circular Dichroism	390
19.3.3	Instrumentation	395
19.3.4	Biological Chromophores that Show Circular Dichroism	395
19.3.5	Applications	396
19.3.6	Potential Pitfalls	398
19.4	Infrared Spectroscopy	398
19.4.1	Bond Vibrations: The Harmonic Oscillator	398
19.4.2	Molecule Geometry, Degrees of Freedom, and Vibrational Modes	400
19.4.3	Instrumentation	402
19.4.4	Applications	403
19.5	Fluorescence	404
19.5.1	General Considerations	404

19.5.2	Instrumentation	406
19.5.3	Quantum Yield and Lifetime	407
19.5.4	Fluorophores and Fluorescent Labeling	408
19.5.4.1	Biological Fluorophores	408
19.5.4.2	Extrinsic Fluorophores and their Introduction into Proteins, Nucleic Acids, and Lipids	409
19.5.5	Applications	418
19.5.5.1	Fluorescence as a Probe for Binding: Equilibrium Titrations	418
19.5.5.2	Fluorescence as a Probe for the Chemical Micro- and Macro-Environment	422
19.5.5.3	Fluorescence and Imaging: Fluorescence Recovery after Photobleaching	423
19.5.6	Potential Pitfalls	424
19.5.7	Fluorescence Quenching	426
19.5.8	Fluorescence Anisotropy	429
19.5.8.1	Principle of Fluorescence Anisotropy	429
19.5.8.2	Applications	431
19.5.8.3	Potential Pitfalls of Polarization/Anisotropy Measurements	432
19.5.9	Time-Resolved Fluorescence	433
19.5.9.1	Measurement of Fluorescence Lifetimes	435
19.5.9.2	Fluorescence Anisotropy Decays and Rotational Correlation Times ...	438
19.5.9.3	Rotational Correlation Time and Molecular Size	439
19.5.9.4	Applications	440
19.5.10	Förster Resonance Energy Transfer	441
19.5.10.1	Principle of FRET	441
19.5.10.2	Experimental Determination of FRET Efficiencies	443
19.5.10.3	Applications	446
19.5.10.4	Potential Pitfalls	449
19.5.10.5	FRET Efficiencies from Lifetimes	449
19.5.10.6	FRET Efficiencies from Single Molecules	452
	Questions	453
	References	455
Chapter 20.	Magnetic Resonance	461
20.1	Nuclear Magnetic Resonance	461
20.1.1	Nuclear Spins and the Zeeman Effect	461
20.1.2	A One-Dimensional NMR Spectrum: Larmor Frequency, Chemical Shift, <i>J</i> -Coupling, and Multiplicity	463
20.1.2.1	The Larmor Frequency	463
20.1.2.2	The Local Magnetic Field and the Chemical Shift	463
20.1.2.3	Scalar Coupling and Multiplets	466
20.1.2.4	Shape of NMR Lines	467
20.1.2.5	Instrumentation	468
20.1.3	The Nuclear Overhauser Effect: Distance Information	468
20.1.4	Magnetization and Its Relaxation to Equilibrium: Fourier Transform-NMR and the Free Induction Decay	472
20.1.5	Two-Dimensional FT-NMR: COSY and NOESY	476
20.1.5.1	Principle of a 2D-FT-NMR Experiment	477
20.1.5.2	Correlated Spectroscopy	478
20.1.5.3	Nuclear Overhauser Enhancement Spectroscopy	479
20.1.5.4	Spin Systems and Sequential Assignment of Protein NMR Spectra ...	479
20.1.5.5	Structure Calculation	483

20.1.6	Extending NMR to Structure Determination of Large Molecules	484
20.1.7	NMR and Dynamics	486
20.1.8	Solid State NMR and Biology	488
20.1.9	NMR and Imaging	489
20.2	Electron Paramagnetic Resonance	490
20.2.1	Principle of Electron Paramagnetic Resonance	490
20.2.2	Spin-Spin Interactions: Hyperfine Coupling of Unpaired Electrons with Nuclei	491
20.2.3	EPR Probes and Spin Labeling	492
20.2.4	EPR as a Probe for Mobility and Dynamics	494
20.2.5	EPR as a Probe for Accessibility	495
20.2.6	Measuring Spin-Spin Distances	496
20.2.7	Distance Determination by Pulsed EPR: PELDOR/DEER	497
	Questions	500
	References	501
Chapter 21.	Solution Scattering	507
21.1	Light Scattering	507
21.1.1	Static Light Scattering	507
21.1.2	Dynamic Light Scattering	511
21.1.3	Raman Scattering	513
21.2	Small Angle Scattering	515
21.2.1	Scattering of X-rays and Neutrons	515
21.2.2	SAS Intensity Distribution	518
21.2.3	Distance Distribution Function	522
21.2.4	Small Angle X-ray Scattering	523
21.2.4.1	SAXS Experiment	523
21.2.4.2	Excluded Volume and Molecular Mass	524
21.2.4.3	Kratky Plot	524
21.2.4.4	Modeling of Scattering Curves	525
21.2.5	Small Angle Neutron Scattering	526
21.2.5.1	Generation of Neutrons	526
21.2.5.2	Contrast Variation	527
	Questions	528
	References	529
Chapter 22.	X-ray Crystallography	531
22.1	Generation of X-rays	532
22.2	Phase Problem and Requirement for Crystals	536
22.3	Crystallization of Macromolecules	536
22.4	Symmetry and Space Groups	542
22.5	X-ray Diffraction from Crystals	547
22.6	Diffraction Data Collection and Analysis	551
22.7	Phasing Methods	554
22.7.1	Isomorphous Replacement	554
22.7.2	Anomalous Diffraction	556
22.7.3	Molecular Replacement	560
22.8	Electron Density and Model Building	562
22.9	Model Refinement and Validation	565
	Questions	568
	References	569
	Online Resources	570

Chapter 23. Imaging and Microscopy	571
23.1 Fluorescence Microscopy	571
23.1.1 Optical Principles of Microscopy	572
23.1.1.1 Focusing and Collecting Light by Optical Lenses.....	572
23.1.1.2 Microscopes: How to Achieve Magnification with Optical Lenses...	574
23.1.1.3 The Diffraction Limit of Optical Resolution	576
23.1.2 Wide-Field Fluorescence Microscopy	578
23.1.3 Confocal Scanning Microscopy	579
23.1.4 Total Internal Reflection Microscopy.....	581
23.1.5 Fluorescence Lifetime Imaging Microscopy	583
23.1.6 Fluorescence (Cross-)Correlation Spectroscopy.....	584
23.1.6.1 Fluorescence Correlation Spectroscopy	585
23.1.6.2 FCS to Monitor Binding Events	587
23.1.6.3 Fluorescence Cross-Correlation Spectroscopy	590
23.1.7 Single-Molecule Fluorescence Microscopy.....	592
23.1.7.1 Principles of Single-Molecule Microscopy	592
23.1.7.2 Why Single Molecules?	595
23.1.7.3 Localization and Tracking of Single Molecules	596
23.1.7.4 Kinetic Information from Single-Molecule Microscopy.....	597
23.1.7.5 Colocalization of Molecules	598
23.1.7.6 Single-Molecule FRET.....	600
23.1.8 Super-Resolution Microscopy.....	605
23.2 Electron Microscopy	608
23.2.1 Principle of Electron Microscopy	608
23.2.2 Sample Preparation.....	609
23.2.3 Image Generation and Analysis	610
23.2.4 Three-Dimensional Electron Microscopy: Cryo-Electron Tomography and Single Particle Cryo-EM	611
23.2.5 Scanning Probe Microscopy: Scanning Tunneling, Scanning Force, and Atomic Force Microscopy	617
Questions	618
References	619
Chapter 24. Force Measurements	623
24.1 Force Spectroscopy by AFM	625
24.2 Optical Tweezers	631
24.3 Magnetic Tweezers	638
Questions	642
References	642
Chapter 25. Transient Kinetic Methods	647
25.1 Stopped Flow	647
25.2 Quench Flow.....	650
25.3 Laser Flash Photolysis	651
25.4 Relaxation Kinetics: Pressure- and Temperature-Jump	653
Questions	654
References	655
Chapter 26. Molecular Mass, Size, and Shape	657
26.1 Mass Spectrometry	657
26.1.1 Ionization.....	658

26.1.1.1	Matrix-Assisted Laser Desorption Ionization	658
26.1.1.2	Electrospray Ionization	659
26.1.2	Ion Storage and Manipulation	660
26.1.2.1	Time of Flight Analysis	660
26.1.2.2	Quadrupoles and Ion Traps	661
26.1.2.3	Orbitraps	664
26.1.2.4	Ion Fragmentation and Sequencing	665
26.1.3	Detection	667
26.1.4	Mass Spectra	669
26.1.5	Applications	669
26.1.5.1	Mass Analysis for the Identification of Molecules	669
26.1.5.2	Isotope Distribution and Isotope Exchange	670
26.1.5.3	Protein Identification from One- and Two-Dimensional Gels	671
26.1.5.4	Native Mass Spectrometry	671
26.1.5.5	Ion Mobility and Molecular Shape	672
26.1.5.6	Identifying Protein-RNA Interaction Sites after Photo-Crosslinking	673
26.1.5.7	Secondary Ion Mass Spectrometry	673
26.1.5.8	Quantitative Mass Spectrometry	674
26.2	Analytical Ultracentrifugation	676
26.2.1	Instrumentation and Detection Systems	676
26.2.2	Behavior of a Molecule in a Gravitational Field	678
26.2.3	Sedimentation Velocity	682
26.2.3.1	Determination of Sedimentation Coefficients	683
26.2.3.2	Solvent and Concentration Dependence of the Sedimentation Coefficient	684
26.2.3.3	Measuring Polydispersity and Association	685
26.2.4	Sedimentation Equilibrium	687
26.2.4.1	Determination of Molecular Mass Using Sedimentation Equilibrium	687
26.2.4.2	Association in Sedimentation Equilibrium	689
26.2.5	Zonal, Band, or Isopycnic Centrifugation	690
26.3	Surface Plasmon Resonance	693
26.3.1	Physical Background of SPR	693
26.3.2	Principle and Information Content of an SPR Experiment	695
26.3.3	Mass Transport Limitation	697
26.3.4	Receptor Immobilization on the Sensor Surface	697
26.3.4.1	Covalent Receptor Immobilization	698
26.3.4.2	Non-Covalent Receptor Immobilization	700
26.3.5	Stoichiometry of Binding in an SPR Experiment	701
26.3.6	Specificity of Binding in an SPR Experiment	702
	Questions	702
	References	706
	Online resources	707

Chapter 27. Calorimetry709

27.1	Isothermal Titration Calorimetry	709
27.1.1	General Principle	709
27.1.2	ITC Data Analysis	711
27.1.3	Origin of Enthalpic Changes	713
27.1.4	Practical Considerations	715
27.1.5	Measuring High Affinities with ITC by Competition	717
27.1.6	Measuring Michaelis-Menten Enzyme Kinetics with ITC	717

27.2	Differential Scanning Calorimetry	720
27.2.1	General Principle	720
27.2.2	Two-State Unfolding of Macromolecules	723
27.2.3	Two-State Unfolding with Subunit Dissociation	725
	Questions	726
	References	726

Appendix

Chapter 28.	Prefixes, Units, Constants	731
28.1	Prefixes	731
28.2	SI (Système International) or Base Units	732
28.3	Derived Units Used in this Book	732
28.4	Natural Constants Used in This Book	733
Chapter 29.	Mathematical Concepts Used in This Book	735
29.1	Sums and Products	735
29.2	Quadratic Equation	736
29.3	Binomial Coefficients	736
29.4	Trigonometry	737
29.5	Logarithms and Exponentials	737
29.6	Differentiation and Integration	739
29.7	Partial fractions	742
29.8	l'Hôpital's rule	743
29.9	Vectors	743
29.9.1	Dot Product	744
29.9.2	Cross Product	744
29.10	Complex Numbers	745
29.11	Basic Elements of Statistics	747
29.12	Error Propagation	748
29.13	Series Expansion	749
29.13.1	Taylor Series	749
29.13.2	Fourier Series	749
29.14	Fourier Transformation	751
29.15	Convolution	753
	Index	755