
CONTENTS

Preface to the First Edition xxi

Preface to the Second Edition xxiii

Acknowledgments xxv

Symbols xxvii

References xxxi

Author Biographies xxxii

Introduction / Why Colloidal Systems Are Important xxxiii

The Colloidal Domain Encompasses Many Biological and Technological Systems xxxiii

Understanding of Colloidal Phenomena Is Advancing Rapidly xxxvi

Association Colloids Display Key Concepts That Guided the Structures of This book xxxvii

1 / Solutes and Solvents, Self-Assembly of Amphiphiles 1

1.1 Amphiphilic Self-Assembly Processes Are Spontaneous, Are Characterized by Start-Stop Features, and Produce Aggregates with Well-Defined Properties 5

1.2 Amphiphilic Molecules Are Liquidlike in Self-Assembled Aggregates 10

1.3 Surfactant Numbers Provide Useful Guides for Predicting Aggregate Structures 13

1.4 Understanding the Origin of Entropy and Enthalpy of Mixing Provides Useful Molecular Insight into Many Colloidal Phenomena 18

1.4.1 The Ideal Mixing Model Provides a Basis for Understanding the Formation of a Miscible Phase 20

1.4.2 The Regular Solution Model Provides a Simple Description of Nonideal Mixing which Ultimately Leads to the Formation of a Liquid Two-Phase System 23

1.5 The Chemical Potential is a Central Thermodynamic Concept in the Description of Multicomponent Systems 25

- 1.5.1 Having an Expression for the Free Energy We Can Determine the Chemical Potential by Differentiation 27
- 1.5.2 Mixtures and Solutions Differ Through the Choice of Standard States 28
- 1.5.3 The Chemical Potential of the Solvent is Often Expressed in Terms of the Osmotic Pressure 29
- 1.5.4 The Chemical Potential Enters into Many Thermodynamic Equalities 30
- 1.5.5 Chemical Potentials Can Be Generalized to Include the Effect of External Fields 31
- 1.6 Understanding Brownian Motion Provides an Important Enabling Concept in Analyzing Colloidal Systems 33
 - 1.6.1 The Diffusional Motion of Individual Molecules Can be Analyzed in Terms of a Random Walk 33
 - 1.6.2 Diffusional Motion Leads to a Net Transport of Molecules in a Concentration Gradient 36
- 1.7 Solvophobicity Drives Amphiphilic Aggregation 37

2 / Surface Chemistry and Monolayers 45

- 2.1 We Can Comprehend Surface Tension in Terms of Surface Free Energy 49
 - 2.1.1 Molecular Origins of Surface Tension Can Be Understood in Terms of the Difference in Interaction Between Molecules in the Bulk and at the Interface 49
 - 2.1.2 Two Complementary Concepts Define Surface Tension: Line of Force and Energy Required to Create New Surface Area 51
 - 2.1.3 The Work of Adhesion and Cohesion Is Related to Surface Tension and Can Determine the Spontaneous Spreading of One Liquid on Another 53
 - 2.1.4 The Young-Laplace Equation Relates Pressure Differences Across a Surface to Its Curvature 57
- 2.2 Several Techniques Measure Surface Tension 59
 - 2.2.1 Surface Tension Governs the Rise of a Liquid in a Capillary Tube 59
 - 2.2.2 The Wilhelmy Plate Method Measures the Change in Weight of a Plate Brought into Contact with a Liquid 61
 - 2.2.3 The Shapes of Sessile and Pendant Drops Can Be Used to Determine Surface or Interfacial Tension 63

- 2.2.4 Contact Angles Yield Information on Solid Surfaces 64
- 2.3 Capillary Condensation, Ostwald Ripening, and Nucleation Are Practical Manifestations of Surface Phenomena 64
 - 2.3.1 Surface Energy Effects Can Cause a Liquid to Condense on a Surface Prior to Saturation in the Bulk Phase 64
 - 2.3.2 Surface Free Energies Govern the Growth of Colloidal Particles 66
 - 2.3.3 Surface Free Energies Oppose the Nucleation of a New Phase 67
 - 2.3.4 Combining the Kelvin Equation with a Kinetic Association Model Provides an Expression for the Rate of Homogeneous Nucleation 69
- 2.4 Thermodynamic Equations That Include Surface Contributions Provide a Fundamental Basis for Characterizing Behavior of Colloidal Particles 73
 - 2.4.1 The Gibbs Model Provides a Powerful Basis for Analyzing Surface Phenomena by Dividing a System into Two Bulk Phases and an Infinitesimally Thin Dividing Surface 73
 - 2.4.2 The Gibbs Adsorption Equation Relates Surface Excess to Surface Tension and the Chemical Potential of the Solute 74
 - 2.4.3 The Langmuir Equation Describes Adsorption at Solid Interfaces Where We Cannot Measure Surface Tension Directly 77
- 2.5 Monolayers Are Two-Dimensional Self-Organizing Systems 78
 - 2.5.1 Monolayers Formed by Soluble Amphiphiles Can Be Characterized by Surface Tension Measurements Using the Gibbs Adsorption Isotherm 78
 - 2.5.2 Monolayers Formed by Insoluble Amphiphiles Behave as Separate Phases and Are More Readily Characterized Using the Langmuir Balance 79
- 2.6 Π_s Versus a_0 Surface Isotherms for Monolayers Containing Insoluble Amphiphiles Parallel P Versus V Isotherms for Bulk Systems 81
 - 2.6.1. The Insoluble Monolayer Displays Several Aggregation States 81
 - 2.6.2 Fluorescence Microscopy Can Visualize the Aggregation State of Monolayers Directly 83

- 2.6.3 The Langmuir-Blodgett Technique Provides a Way to Deposit Monolayers or Multilayers onto Solid Surfaces 85
- 2.7 Scanning Tunneling and Atomic Force Microscopies Permit Imaging of Molecular Structures at Solid Interfaces 85

3 / Electrostatic Interactions in Colloidal Systems 99

- 3.1 Intermolecular Interactions Often Can Be Expressed Conveniently as the Sum of Five Terms 104
- 3.2 Multipole Expansion of the Charge Distribution Provides a Convenient Way to Express Electrostatic Interactions Between Molecules 105
- 3.3 When Electrostatic Interactions Are Smaller than the Thermal Energy, We Can Use Angle-Averaged Potentials to Evaluate Them and Obtain the Free Energy 114
- 3.4 Induced Dipoles Contribute to Electrostatic Interactions 115
- 3.5 Separating Ion-Ion Interactions from Contributions of Dipoles and Higher Multipoles in the Poisson Equation Simplifies Dealing with Condensed Phases 118
- 3.6 The Poisson Equation Containing Solvent-Averaged Properties Describes the Free Energy of Ion Solvation 125
- 3.7 Self Assembly, Ion Adsorption, and Surface Titration Play an Important Role in Determining Properties of Charged Interfaces 127
- 3.8 The Poisson-Boltzmann Equation Can be Used to Calculate the Ion Distribution in Solution 131
- 3.8.1 The Gouy-Chapman Theory Relates Surface Charge Density to Surface Potential and Ion Distribution Outside a Planar Surface 131
- 3.8.2 Linearizing the Poisson-Boltzmann Equation Leads to Exponentially Decaying Potentials and the Debye-Hückel Theory 136
- 3.8.3 The Gouy-Chapman Theory Provides Insight into Ion Distribution near Charged Surfaces 138
- 3.9 The Electrostatic Free Energy is Composed of One Contribution from the Direct Charge-Charge Interaction and One Due to the Entropy of the Nonuniform Distribution of Ions in Solution 143
- 3.9.1 There Are Several Equivalent Expressions for the Electrostatic Free Energy 143
- 3.9.2 In the Debye-Hückel Theory the Electrostatic Contribution to the Chemical Potential of

an Ion is Obtained by a Charging
Process 145

3.9.3 The Electrostatic Free Energy of a Planar
Charged Surface Can Be Calculated in Closed
Form 146

4 / Structure and Properties of Micelles 153

4.1 Micelle Formation is a Cooperative Association
Process 157

4.1.1 Several Models Usefully Describe Micellar
Aggregation 157

4.1.2 Thermodynamics of Micelle Formation
Provide Useful Relationships Between Free
Energies and Surfactant Chemical Potentials
and Explicit Relations for Enthalpy and
Entropy 163

4.2 We Can Measure Critical Micelle Concentrations,
Aggregation Numbers, and Characteristic Lifetimes
by a Number of Methods 165

4.2.1 We Can Determine CMCs by Surface Tension,
Conductance, and Surfactant Ion Electrode
Measurements 165

4.2.2 Micellar Aggregation Numbers Can Be
Measured Most Simply by Light Scattering or
with Fluorescent Probes 170

4.2.3 Kinetic Experiments Provide Valuable Insight
into the Time Scales of Dynamic Processes
in Micellar Solutions 177

4.2.4 Dynamics of Solutes Dissolved in Micelles
Provide a Measure of the Time Scales for
Solubilization Processes 180

4.2.5 Diffusion Plays an Important Role in Virtually
All Micellar Processes 181

4.3 The Properties of Many Micellar Solutions Can Be
Analyzed Quantitatively 183

4.3.1 The Poisson-Boltzmann Equation Describes
Head Group Interactions in Ionic
Micelles 185

4.3.2 Variations in the CMC Caused by Electrostatic
Effects Are Well Predicted by the Poisson-
Boltzmann Equation 188

4.3.3 The Contribution of the Solvophobic Free
Energy $\Delta G(HP)$ Decreases when Micelles
Form in Nonaqueous Solvents 191

4.3.4 Enthalpy and Entropy of Micellization
Change Much More Rapidly with
Temperature than the Free Energy 191

4.3.5 Unchanged Surfactants Have Much Lower
CMCs than Ionic Ones 193

4.3.6 Micelles Can Grow in Size to Short Rods,

- Long Polymer-Like Threads, and Even
Branched Infinite Aggregates 197
- 4.4 Micellar Solutions Play a Key Role in Many
Industrial and Biological Processes 198
- 4.4.1 Commercial Detergents Contain a Mixture of
Surfactants 198
- 4.4.2 Digestion of Fats Requires Solubilization by
Bile Salt Micelles 202
- 4.4.3 Solubilization in Micellar Solutions Involves
a Complex Combination of Solution Flow
and Surface Chemical Kinetics 204
- 4.4.4 Micellar Catalysis Exploits the Large Surface
Areas Associated with Micelles and Also
Illustrates the Graham Equation 210

5 / Forces In Colloidal Systems 217

- 5.1 Electrostatic Double-Layer Forces Are
Long-Ranged 225
- 5.1.1 A Repulsive Electrostatic Force Exists
Between a Charged and a Neutral
Surface 225
- 5.1.2 We Can Solve the Poisson-Boltzmann
Equation when Only Counterions Are Present
Outside the Charged Surface 229
- 5.1.3 Ion Concentration at the Midplane
Determines the Force Between Two
Identically Charged Surfaces 231
- 5.1.4 The Bulk Solution Often Provides a Suitable
Reference for the Potential 233
- 5.1.5 Two Surfaces with Equal Signs but Different
Magnitudes of Charge Always Repel Each
Other 236
- 5.1.6 As Surfaces Bearing Opposite Signs Move
Closer Together, Long-Range Electrostatic
Attraction Changes to Repulsion 238
- 5.2 Van der Waals Forces Comprise Quantum
Mechanical Dispersion, Electrostatic Keesom, and
Debye Forces 239
- 5.2.1 An Attractive Dispersion Force of Quantum
Mechanical Origin Operates Between Any
Two Molecules 239
- 5.2.2 We Can Calculate the Dispersion Interaction
Between Two Colloidal Particles by Summing
Over the Molecules on a Pairwise Basis 240
- 5.2.3 The Presence of a Medium Between Two
Interacting Particles Modifies the Magnitude
of the Hamaker Constant 245
- 5.2.4 The Derjaguin Approximation Relates the
Force Between Curved Surfaces to the
Interaction Energy Between Flat
Surfaces 248

- 5.2.5 The Lifshitz Theory Provides a Unified Description of van der Waals Forces Between Colloidal Particles 250
- 5.3 Electrostatic Interactions Generate Attractions by Correlations 254
 - 5.3.1 Ion Correlations Can Turn the Double-Layer Interaction Attractive 254
 - 5.3.2 Surface Dipoles Correlate to Yield an Attraction 256
 - 5.3.3 Domain Correlations Can Generate Long-Range Forces 258
- 5.4 Density Variations Can Generate Attractive and Oscillatory Forces 259
 - 5.4.1 Packing Forces Produce Oscillatory Force Curves with a Period Determined by Solvent Size 261
 - 5.4.2 Capillary Phase Separation Yields an Attractive Force 264
 - 5.4.3 A Non-Adsorbing Solute Creates an Attractive Depletion Force 269
 - 5.4.4 Adsorption Introduces on Average an Increased Repulsion 271
- 5.5 Entropy Effects Are Important for Understanding the Forces Between Liquidlike Surfaces 275
 - 5.5.1 Reducing Polymer Configurational Freedom Generates a Repulsive Force 276
 - 5.5.2 Short Range Forces That Encompass a Variety of Interactions Play Key Roles in Stabilizing Colloidal Systems 276
 - 5.5.3 Undulation Forces Can Play an Important Role in the Interaction of Fluid Bilayers 278
- 5.6 The Thermodynamic Interpretation of the Hydrophobic Interaction Is Problematic Due to Entropy-Enthalpy Compensation 279
 - 5.6.1 Understanding the Mysteries of Water 279
 - 5.6.2 Strong Attraction Exists Between Hydrophobic Surfaces Although Experiments Have Failed to Establish the Distance-Dependence of this Force 286
- 5.7 Hydrodynamic Interactions Can Modulate Interaction Forces 289

6 / Bilayer Systems 295

- 6.1 Bilayers Show a Rich Variation with Respect to Local Chemical Structure and Global Folding 300
 - 6.1.1 Many Amphiphiles Form a Bilayer Structure 300
 - 6.1.2 Membrane Lipids Exhibit Chemical Variations on a Common Theme 301
 - 6.1.3 Comparing the Properties of Spherical Micelles and Bilayers Provides Useful Insight

- into the Many Distinctive Molecular Properties of Bilayers 303
- 6.1.4 Pure Amphiphiles Form a Range of Bulk Bilayer Phases 306
- 6.1.5 Vesicles Can be Formed by Several Methods 308
- 6.2 Complete Characterization of Bilayers Requires a Variety of Techniques 310
- 6.2.1 X-Ray Diffraction Uniquely Identifies a Liquid Crystalline Structure and Its Dimensions 310
- 6.2.2 Microscopy Yields Images of Aggregate Structures 313
- 6.2.3 Nuclear Magnetic Resonance Provides a Picture of Bilayer Structure on the Molecular Level 315
- 6.2.4 Calorimetry Monitors Phase Transitions and Measures Transition Enthalpies 318
- 6.2.5 We Can Accurately Measure Interbilayer Forces 320
- 6.2.6 Measurements of Interbilayer Forces Play a Key Role in Testing Theories of Surface Interactions 325
- 6.3 The Lipid Bilayer Membranes has Three Basic Functions 327
- 6.3.1 Diffusional Processes Are Always Operating in the Living System 328
- 6.3.2 The Lipid Membrane Is a Solvent for Membrane Proteins 335
- 6.3.3 Cell Membranes Fold into a Range of Global Structures 337
- 6.4 Transmembrane Transport of Small Solutes Is a Central Physiological Process 340
- 6.4.1 Solutes Can Be Transported across the Membrane by Carriers, in Channels, by Pumps, or by Endocytosis/Exocytosis 340
- 6.4.2 The Chemiosmotic Mechanism Involves Transformations Between Chemical, Electrical, and Entropic Forms of Free Energy Through Transmembrane Transport Processes 343
- 6.4.3 Propagation of a Nerve Signal Involves a Series of Transmembrane Transport Processes 346

7 / Polymers in Colloidal Systems 351

- 7.1 Polymers in Solution 355
- 7.1.1 Chain Configurational Entropy and Monomer-Monomer Interactions Determine the Configuration of a Single Polymer Chain 358

- 7.1.2 Persistence Length Describes the Stiffness of a Polymer Chain 360
- 7.1.3 When Polymers Dissolve into a Solvent Many More Coil Configurations Become Accessible 362
- 7.1.4 Charged Polymer Chains Display a More Extended Conformation 363
- 7.1.5 Protein Folding Is the Result of a Delicate Balance Between Hydrophobic and Hydrophilic Interactions and Configurational Entropy 365
- 7.1.6 Scattering Techniques Provide Information about Molecular Weight and Chain Conformation 366
- 7.1.7 Polymer Self-Diffusion and Solution Viscosity Reflect the Dynamic and Structural Properties of a Polymer Coil 370
- 7.2 Thermodynamic and Transport Properties of Polymer Solution Change Dramatically with Concentration 372
 - 7.2.1 Different Concentration Regimes Must Be Distinguished to Describe a Polymer Solution 372
 - 7.2.2 The Semidilute Regime is Well Described by the Flory-Huggins Theory 375
 - 7.2.3 In a Semidilute or Concentrated Solution, Polymer Diffusion Can Occur Through Reptation 376
 - 7.2.4 Polymer Solutions Show a Wide Range of Rheological Properties 379
- 7.3 Polymers May Associate to Form a Variety of Structures 382
 - 7.3.1 Block Copolymers Show the Same Self-Assembly Properties as Surfactants 382
 - 7.3.2 Polymers with Amphiphilic Monomer Units Often Form Ordered Helix Structures 383
 - 7.3.3 Polymers Form Gels Through Chemical Crosslinking and by Self-Association 386
 - 7.3.4 Polymers Facilitate the Self-Assembly of Amphiphiles 387
- 7.4 Polymers at Surfaces Play an Important Role in Colloidal Systems 390
 - 7.4.1 Polymers Can Be Attached to a Surface by Spontaneous Adsorption or by Grafting 390
 - 7.4.2 Kinetics Often Determines the Outcome of a Polymer Adsorption Process 393
 - 7.4.3 Forces Between Surfaces Change Drastically when Polymers Adsorb 393

8 / Colloidal Stability 401

- 8.1 Colloidal Stability Involves Both Kinetic and Thermodynamic Considerations 406
 - 8.1.1 The Interaction Potential Between Particles Determines Kinetic Behavior 406
 - 8.1.2 Particles Deformed upon Aggregation Change the Effective Interaction Potential 408
- 8.2 The DLVO Theory Provides Our Basic Framework for Thinking About Colloidal Interactions 409
 - 8.2.1 Competition Between Attractive van der Waals and Repulsive Double-Layer Forces Determines the Stability or Instability of Many Colloidal Systems 409
 - 8.2.2 The Critical Coagulation Concentration Is Sensitive to Counterion Valency 412
 - 8.2.3 A Colloidal Suspension Can Be Stabilized by Adsorbing Surfactants or Polymers 415
- 8.3 Kinetics of Aggregation Allow Us To Predict How Fast Colloidal Systems Will Coagulate 417
 - 8.3.1 We Can Determine the Binary Rate Constant for Rapid Aggregation from the Diffusional Motion 417
 - 8.3.2 We Can Calculate Complete Aggregation Kinetics if We Assume That Rate Constants Are Practically Independent of Particle Size 420
 - 8.3.3 Kinetics of Slow Flocculation Depends Critically on Barrier Height 424
 - 8.3.4 Aggregates of Colloidal Particles Can Show Fractal Properties 426
- 8.4 Electrokinetic Phenomena Are Used to Determine Zeta Potentials of Charged Surfaces and Particles 428
 - 8.4.1 We Can Relate the Electrophoretic Velocity of a Colloidal Particle to the Electrical Potential at the Slip Plane 429
 - 8.4.2 We Can Determine the Zeta Potential for a Surface by Measuring the Streaming Potential 434
 - 8.4.3 Electro-osmosis Provides Another Way to Measure the Zeta-Potential 436

9 / Colloidal Sols 443

- 9.1 Colloidal Sols Formed by Dispersion or Condensation Processes Usually Are Heterogeneous 448

- 9.1.1 Controlling Nucleation and Growth Steps Can Produce Monodisperse Sols 449
- 9.2 The Concentration of Silver and Iodide Ions Determines the Surface Potential of Silver Iodide Sols 452
 - 9.2.1 Potential-Determining Ions Play an Important Role in Controlling Stability 455
- 9.3 Clays Are Colloidal Sols Whose Surface Charge Density Reflects the Chemistry of Their Crystal Structure 457
 - 9.3.1 Directly Measurable Interaction Forces Between Two Mica Surfaces Provide Insight into the Complexities of Colloidal Systems 460
 - 9.3.2 Coagulated Structures Complicate the Colloidal Stability of Clay Sols 463
- 9.4 Monodisperse Latex Spheres Can Model Various States of Matter as Well as the Phase Transformations Between Them 465
 - 9.4.1 Long-Range Electrostatic Repulsions Dominate the Solution Behavior of Ionic Latex Spheres 466
 - 9.4.2 Sterically Stabilized Latex Spheres Show Only Short-Range Interactions and Form Structured Solutions Only at Higher Concentrations 470
- 9.5 Homocoagulation and Heterocoagulation Occur Simultaneously in Many Colloidal Systems 473
- 9.6 Aerosols Involve Particles in the Gas Phase 479
 - 9.6.1 Some Aerosols Occur Naturally, But Many Others Are Produced in Technical Processes 479
 - 9.6.2 Aerosol Properties Differ Quantitatively from Those of Other Colloidal Dispersions in Three Respects 480
 - 9.6.3 Aerosol Particles Interact by van der Waals Forces as Well as Electrostatically and Hydrodynamically 481
 - 9.6.4 Aerosol Particles Possess Three Motion Regimes 483

10 / Phase Equilibria, Phase Diagrams, and Their Application 489

- 10.1 Phase Diagrams Depicting Colloidal Systems Are Generally Richer Than Those for Molecular Systems 493
 - 10.1.1 Several Uncommon Aggregation States Appear in Colloidal Systems 493
 - 10.1.2 The Gibbs Phase Rule Guides the Thermodynamic Description of Phase Equilibria 498

- 10.1.3 In a Multicomponent System with Two Phases in Equilibrium, the Chemical Potential of Each Component Is the Same in Both Phases 499
- 10.1.4 Phase Diagrams Conveniently Represent Phase Equilibria 501
- 10.1.5 Determining Phase Equilibria Is a Demanding Task 503
- 10.2 Examples Illustrate the Importance of Phase Equilibria for Colloidal Systems 505
 - 10.2.1 Purely Repulsive Interactions Can Promote the Formation of Ordered Phases 507
 - 10.2.2 Ionic Surfactants Self-Assemble into a Multiplicity of Isotropic and Liquid Crystalline Phases 507
 - 10.2.3 Temperature Changes Dramatically Affect Phase Equilibria for Nonionic Surfactants 509
 - 10.2.4 Block Copolymers Exhibit as Rich a Phase Behavior as Surfactants 510
 - 10.2.5 Monomolecular Films Show a Rich Phase Behavior 512
- 10.3 We Obtain an Understanding of the Factors That Determine Phase Equilibria by Calculating Phase Diagrams 514
 - 10.3.1 The Regular Solution Model Illustrates Liquid-Liquid Phase Separation 514
 - 10.3.2 Liquid State Miscibility and Solid State Demixing Lead to a Characteristic Phase Diagram 517
 - 10.3.3 Two Lipids that Exhibit Different Melting Points but Ideal Mixing in Both the Gel and Liquid Crystalline Phases Produce a Simple Phase Diagram 520
 - 10.3.4 The Presence of an Impurity Broadens a Phase Transition by Introducing a Two-Phase Area 522
 - 10.3.5 The Short Range Stabilizing Force Influences the Equilibrium Between Liquid Crystalline and Gel Phases in Lecithin-Water Systems 524
 - 10.3.6 The Isotropic to Nematic Transition can be Caused by an Orientation Dependent Excluded Volume 526
- 10.4 Continuous Phase Transitions Can Be Described by Critical Exponents 531
 - 10.4.1 Phase Changes Can Be Continuous 531
 - 10.4.2 Continuous Transitions Are Characterized by the Values of Critical Exponents 532
 - 10.4.3 We Can Use the Regular Solution Theory to

- Illustrate the Ising Model and to Calculate Mean Field Critical Exponents 534
- 10.4.4 Nonionic Surfactants Show a Critical Demixing When the Temperature Increases 535
- 10.4.5 The Term Continuous Phase Transition Sometimes Characterizes Less Well-Defined Phase Changes 536

11 / Micro- and Macroemulsions 539

- 11.1 Surfactant Form a Semiflexible Elastic Film at Interfaces 544
 - 11.1.1 We Can Characterize the Elastic Properties of a Film Through Five Phenomenological Constants 544
 - 11.1.2 With Some Effort We Can Measure Elastic Constants 548
- 11.2 Microemulsions Are Thermodynamically Stable Isotropic Solutions That Display a Range of Self-Assembly Structures 550
 - 11.2.1 Microemulsions Can Contain Spherical Drops or Bicontinuous Structures 550
 - 11.2.2 Temperature Controls the Structure and Stability of Nonionic Surfactant Microemulsions 553
 - 11.2.3 We Often Need Electrolytes to Obtain Microemulsions for Ionic Surfactants 559
 - 11.2.4 DDAB Double-Chain Surfactants Show Bicontinuous Inverted Structures 561
- 11.3 Macroemulsions Consist of Drops of One Liquid in Another 568
 - 11.3.1 Forming Macroemulsions Usually Requires Mechanical or Chemical Energy 568
 - 11.3.2 Turbulent Flow during the Mixing Process Governs Droplet Size 571
 - 11.3.3 A Chemical Nonequilibrium State Can Induce Emulsification 573
 - 11.3.4 A Number of Different Mechanisms Affect the Evolution of an Emulsion 575
 - 11.3.5 To Stabilize an Emulsion, the Dispersed Phase in Different Drops Should Be Prevented from Reaching Molecular Contact 577
 - 11.3.6 Emulsion Structure and Stability Depend on the Properties of the Surfactant Film 580
 - 11.3.7 We Can Catalyze Coalescence by Changing the Spontaneous Curvature and by Inducing Depletion Attraction 588
- 11.4 Foams Consist of Gas Bubbles Dispersed in a Liquid or Solid Medium 590

- 11.4.1 A Surface Film Develops on Bubbles as They Rise 591
- 11.4.2 Concentrated Foams Consist of Polyhedral Gas Compartments Packed in an Intriguing Way 593
- 11.4.3 Foams Disintegrate by Ostwald Ripening and Film Rupture 594
- 11.4.4 Macroscopic Liquid Films Stabilized by Surfactants Can Be Used to Study Surface Forces and Film Stability 595

12 / Epilogue 601

- 12.1 Colloid Science has Changed from a Reductionistic to a Holistic Perspective During this Century 602
- 12.2 Quantum Mechanics, Statistical Mechanics, and Thermodynamics Provide the Conceptual Basis for Describing the Equilibrium Properties of the Colloidal Domain 604
- 12.3 Intramolecular, Intermolecular, and Surface Forces Determine the Equilibrium Properties and Structure of Colloidal Systems 606
- 12.4 Crucial Interplay Between the Organizing Energy and the Randomizing Entropy Governs the Colloidal World 608
- 12.5 The Dynamic Properties of a Colloidal System Arise from a Combination of the Thermal Brownian Motion of the Individual Particles and the Collective Motion of the Media 611

Index 613