

Contents

| | | |
|----------|-------------------------------------------------------------------------------------|----|
| 1 | Introduction | 1 |
| 1.1 | Introduction. | 1 |
| 1.2 | Solids. | 2 |
| 1.3 | Liquids. | 5 |
| 1.4 | Suspensions. | 10 |
| | 1.4.1 Phase Separation | 10 |
| | 1.4.2 Effect of Particles on Behaviour of the Mixture | 11 |
| | 1.4.3 Other Effects. | 12 |
| 1.5 | Colloids | 15 |
| | 1.5.1 Colloidal Interactions. | 16 |
| | 1.5.2 Yield Stress | 16 |
| | 1.5.3 Thixotropy | 18 |
| 1.6 | Polymers. | 21 |
| | 1.6.1 Properties of Polymer Chains | 21 |
| | 1.6.2 Polymers in Solution | 22 |
| | 1.6.3 Viscoelasticity. | 23 |
| | 1.6.4 Other Properties of Polymers | 25 |
| 1.7 | Emulsions. | 26 |
| 1.8 | Foams. | 29 |
| 1.9 | Granular Materials | 30 |
| 1.10 | Real-Life Materials | 33 |
| | Reference | 33 |
| 2 | Simple Materials | 35 |
| 2.1 | Introduction. | 35 |
| 2.2 | Interactions Between Elementary Components and States of Simple Matter | 37 |
| | 2.2.1 Elementary Components. | 37 |
| | 2.2.2 Thermal Agitation | 37 |
| | 2.2.3 Interaction Potential | 38 |
| | 2.2.4 Van der Waals Forces | 39 |
| | 2.2.5 Chemical Bonds | 40 |
| | 2.2.6 Born Repulsion Force. | 40 |
| | 2.2.7 Balance of Forces | 40 |

| | | |
|----------|------------------------------------------------------------------------------|-----------|
| | 2.2.8 Hydrogen Bond and Hydrophobic Forces | 41 |
| | 2.2.9 States of Simple Matter | 42 |
| 2.3 | Gaseous State | 43 |
| | 2.3.1 Velocity Distribution | 43 |
| | 2.3.2 Mean Free Path | 46 |
| | 2.3.3 Entropy | 46 |
| | 2.3.4 Ideal Gas Law | 48 |
| | 2.3.5 Kinetic Theory | 50 |
| 2.4 | Liquid State | 55 |
| | 2.4.1 Transition from Gaseous State to Liquid State | 55 |
| | 2.4.2 Structure | 60 |
| | 2.4.3 Deformation | 60 |
| | 2.4.4 Flow | 61 |
| | 2.4.5 Rheophysical Model | 63 |
| | 2.4.6 Interfacial Tension | 65 |
| 2.5 | Solid State | 66 |
| | 2.5.1 Structures and Interactions | 66 |
| | 2.5.2 Microrheology in the Solid Regime | 67 |
| | 2.5.3 Elongation | 68 |
| | 2.5.4 Behaviour Under Simple Shear | 69 |
| | 2.5.5 Compressibility | 71 |
| | 2.5.6 Maximal Mechanical Strength | 72 |
| | 2.5.7 Solid-Liquid Transition | 75 |
| | 2.5.8 Solid-Gas Transition | 75 |
| 2.6 | Glassy State | 76 |
| | 2.6.1 Glasses | 76 |
| | 2.6.2 Glass Transition | 76 |
| | 2.6.3 Mechanical Behaviour Associated with the Glass Transition | 77 |
| | 2.6.4 Viscosity of Glasses | 79 |
| 3 | Suspensions | 81 |
| | 3.1 Introduction | 81 |
| | 3.2 Preparing a Suspension | 83 |
| | 3.2.1 Geometry | 83 |
| | 3.2.2 Volume Fraction | 84 |
| | 3.2.3 Energy Involved in Creating the Suspension | 85 |
| | 3.2.4 Dispersing the Particles | 87 |
| | 3.2.5 How Many Particles can be Put in Suspension? | 87 |
| | 3.2.6 Resistance of the Liquid to Particle Displacement | 89 |
| | 3.2.7 Stability | 92 |
| | 3.3 Effect of Particles on the Behaviour of the Mixture | 95 |
| | 3.4 Effect of Concentration | 97 |
| | 3.4.1 General Considerations | 97 |

| | | |
|----------|---------------------------------------------------------------------------------------------|------------|
| 3.4.2 | Concentration Regimes | 99 |
| 3.4.3 | Dilute Suspension | 100 |
| 3.4.4 | Non-dilute Suspension | 101 |
| 3.5 | Effect of Particle Anisotropy | 104 |
| 3.5.1 | Ideal Anisotropic Particles: Spheroids | 104 |
| 3.5.2 | Effect on Viscosity of Anisotropic Particles with Constant Uniform Orientation | 105 |
| 3.5.3 | Particle Rotation in a Fluid Under Simple Shear | 105 |
| 3.5.4 | Effect of Concentration | 108 |
| 3.6 | Effect of Non-uniform Particle Concentration | 109 |
| 3.7 | Shear Thickening | 113 |
| 3.8 | Suspensions in a Yield Stress Fluid | 115 |
| 3.8.1 | Displacement of an Object Through a Yield Stress Fluid | 115 |
| 3.8.2 | Stability | 116 |
| 3.8.3 | Behaviour | 117 |
| | References | 118 |
| 4 | Polymers | 121 |
| 4.1 | Introduction | 121 |
| 4.2 | Structure | 123 |
| 4.2.1 | Apparent Length of a Chain | 123 |
| 4.2.2 | Distribution of Apparent Chain Lengths | 124 |
| 4.2.3 | Radius of Gyration | 126 |
| 4.2.4 | Extension of a Chain Under Traction | 127 |
| 4.2.5 | Persistence Length | 129 |
| 4.3 | Polymers in Solution | 132 |
| 4.3.1 | Configurational Free Energy | 132 |
| 4.3.2 | Free Energy Associated with Interactions Between Molecules | 133 |
| 4.3.3 | Total Free Energy and Chain Size | 135 |
| 4.4 | Several Chains in Solution | 136 |
| 4.4.1 | Dilute Regime | 137 |
| 4.4.2 | Semi-dilute Regime | 138 |
| 4.4.3 | Concentrated Regime | 139 |
| 4.4.4 | Entanglement | 140 |
| 4.5 | Cross-Linked Polymers and Polymer Gels | 142 |
| 4.6 | Mechanical Behaviour of Liquid Polymers | 144 |
| 4.6.1 | General Considerations | 144 |
| 4.6.2 | Dilute Regime | 147 |
| 4.6.3 | Concentrated Regime | 150 |
| 4.6.4 | Semi-dilute Regime | 154 |
| 4.7 | Effect of Temperature | 155 |

| | | |
|----------|--------------------------------------------------------------------------------|-----|
| 5 | Colloids | 157 |
| 5.1 | Introduction. | 157 |
| 5.2 | Brownian Motion. | 159 |
| 5.2.1 | Basic Principles. | 159 |
| 5.2.2 | Diffusion | 162 |
| 5.2.3 | Rotational Diffusion. | 164 |
| 5.2.4 | Osmotic Pressure | 165 |
| 5.2.5 | Sedimentation and Brownian Diffusion | 165 |
| 5.3 | Van der Waals Forces | 167 |
| 5.4 | Electrostatic Forces | 170 |
| 5.5 | Effects Due to Adsorbed Polymers. | 173 |
| 5.6 | Depletion Interactions. | 176 |
| 5.7 | Balance of Interactions | 177 |
| 5.8 | Behaviour of Repulsive Systems | 180 |
| 5.8.1 | Hard Repulsive Suspensions | 180 |
| 5.8.2 | Soft Repulsive Suspensions. | 184 |
| 5.9 | Attractive Systems | 190 |
| 5.9.1 | Structure. | 190 |
| 5.9.2 | Behaviour of Attractive Suspensions | 194 |
| 5.10 | Pasty-Hydrodynamic Transition. | 198 |
| | References | 199 |
| 6 | Emulsions and Foams | 201 |
| 6.1 | Introduction. | 201 |
| 6.2 | Physical Properties on the Scale of the Inclusions | 203 |
| 6.2.1 | Energy | 203 |
| 6.2.2 | Pressure Difference Across an Interface | 203 |
| 6.2.3 | Deformation of a Fluid Inclusion at Zero Speed and Constant Volume. | 204 |
| 6.2.4 | Displacement of an Inclusion in a Liquid at Rest | 206 |
| 6.2.5 | Sedimentation or Creaming. | 207 |
| 6.3 | Preparation | 207 |
| 6.3.1 | General Considerations. | 207 |
| 6.3.2 | Forming Inclusions by Deformation. | 209 |
| 6.4 | Stability | 212 |
| 6.4.1 | Coalescence and Stabilisation | 212 |
| 6.4.2 | Ostwald Ripening | 216 |
| 6.5 | Behaviour | 218 |
| 6.5.1 | General Considerations. | 218 |
| 6.5.2 | Concentration Regimes. | 220 |
| 6.5.3 | Dilute Regime. | 222 |
| 6.5.4 | Semi-dilute Regime | 224 |
| 6.5.5 | Concentrated Regime | 225 |
| | References | 230 |

| | |
|---------------------------------------------------------------------|-----|
| 7 Granular Materials | 231 |
| 7.1 Introduction | 231 |
| 7.2 Main Types of Direct Interaction | 233 |
| 7.2.1 Lubricated Contact | 233 |
| 7.2.2 Frictional Contact | 235 |
| 7.2.3 Collision | 236 |
| 7.3 Role of Configuration | 238 |
| 7.3.1 Basic Principles | 238 |
| 7.3.2 Dilatancy | 239 |
| 7.3.3 Settling | 240 |
| 7.3.4 State of the System | 240 |
| 7.4 Regimes of Behaviour | 241 |
| 7.5 Frictional Regime | 243 |
| 7.5.1 Simple Shear | 243 |
| 7.5.2 Constitutive Law | 245 |
| 7.5.3 Applications to Quasi-Static Flows | 248 |
| 7.6 Collisional Regime | 251 |
| 7.7 Intermediate Regimes | 254 |
| 7.7.1 Transition from Frictional to Collisional Regime | 254 |
| 7.7.2 Transition from Frictional to Lubricated Regime | 254 |
| References | 258 |
| | |
| 8 Rheometry | 261 |
| 8.1 Introduction | 261 |
| 8.2 Basic Geometries | 262 |
| 8.2.1 Parallel Disk Rheometer | 263 |
| 8.2.2 Cone–Plate Rheometer | 265 |
| 8.2.3 Concentric Cylinder Rheometer | 265 |
| 8.2.4 Flow in a Duct | 267 |
| 8.3 Perturbing Factors in Rheometry | 269 |
| 8.3.1 Perturbations of the Sample Volume | 270 |
| 8.3.2 Slipping on the Walls | 271 |
| 8.3.3 Migration | 273 |
| 8.3.4 Shear Bands | 274 |
| 8.3.5 Instability Associated with a Decreasing Flow Curve | 276 |
| 8.3.6 Other Perturbing Factors | 277 |
| 8.4 Experimental Procedures | 278 |
| 8.4.1 Choosing the Geometry | 278 |
| 8.4.2 Preparing the Sample | 279 |
| 8.4.3 Flow Curve | 279 |
| 8.4.4 Solid–Liquid Transition | 281 |
| 8.5 Practical Measurement Techniques | 282 |
| 8.5.1 Squeeze Tests | 282 |
| 8.5.2 Inclined Plane | 285 |

| | |
|-----------------------------------------------------|-----|
| Appendix A: Fluid Mechanics | 289 |
| Appendix B: Elements of Thermodynamics | 311 |
| Index | 317 |