

Table of Contents

Chapter 1. Introduction to Small Particles	1
1. Small Particles and Materials	1
2. How Many Atoms/molecules Are There in Small Particles?	4
3. How Small Is a Colloidal Particle?	8
4. What Materials Form Small Particles?	9
5. Small Particles by Polymerization of Monomers	9
5.1. Organic Monomers	10
5.2. Inorganic Salts	10
5.3. Polymerization of Silica	10
5.4. Metal-Organic Compounds	10
6. Clusters—"Soccer Balls"	10
7. Other Specialized Methods for Making Small Particles	12
7.1. Grinding	12
7.2. Pyrolytic Methods	13
8. Characterization of Small Particles and Structure of Small Particles	13
8.1. Introduction	13
8.2. General Methods	14
8.3. Special Methods	23
 Chapter 2. Small Particles of Silica	 29
A. Solubility and Rate of Dissolution of Silica	30
1. Solubility of Silica	30
2. Solubility and Particle Size	32
3. Sources of Monomeric Silica	34
4. Rate of Dissolution of Silica	34
B. Polymerization of Silica	36
1. Polymerization of Monomeric Silica	36
1.1. Polymerization at pH 1.5-7	38
1.2. Polymerization above pH 7	41
1.3. Polymerization below pH 1.5-2	43
2. Hydrolysis and Condensation of Silicon Alkoxides	43
2.1. Preparation of Monodisperse Silica Spheres	45
2.2. Structure of SFB-particles	46
2.3. Growth Mechanism	47
2.4. Factors affecting the Particle Size of SFB Particles	48
C. Water-soluble Silicates	50
1. Constitution of Solutions of Alkali Silicates	51
2. Dilution of Concentrated Alkali Silicate Solutions	55
3. Association of Sodium Ions with Silicate Ions	57
4. Acidity of Silanol Groups	59
5. Calculation of Particle Size	59
6. Manufacture of Soluble Alkali Silicates	61
7. Uses of Soluble Alkali Silicates	63
D. Silica Sols	67

1. Formation of Sol Particles	67
2. Processes for Making Silica Sols	69
2.1. Column Processes	70
2.2. Concentrated Sol "Consol" Process	77
2.3. Autoclave Process	78
2.4. Aggregation Methods - Stöber Sols	79
3. Commercial Silica Sols and their Uses	80
Chapter 3. Small Particles of Hydrous Metal Oxides	85
Introduction	86
A. Hydrolysis	86
1. Fundamental Concepts	87
2. Hydrolysis of Metal Cations	88
3. Mononuclear Complexes	88
4. Polynuclear Complexes	90
5. Different kinds of Complexes	92
6. Formation of Small Particles	94
7. Effect of the Anion	95
B. Hydrolysis of Some Metal Salts	96
1. Hydrolysis of Al^{3+}	96
1.1. Aluminum Species in Aqueous Solutions	96
1.2. Colloidal Boehmite	99
2. Hydrolysis of Fe^{3+}	117
2.1. Polymerization and Formation of Colloidal Particles	120
3. Hydrolysis of Ti^{4+}	123
3.1. Polymerization and Formation of Colloidal Particles	125
4. Hydrolysis of Zr^{4+}	127
4.1. Polymerization and Formation of Colloidal Particles	129
5. Hydrolysis of Cr^{3+}	131
5.1. Polymerization and Formation of Colloidal Particles	131
6. Hydrolysis of Y^{3+} and Lanthanide ions, Ln^{3+}	133
6.1. Polymerization and Formation of Colloidal Particles	134
7. Hydrolysis of Ce^{4+}	135
7.1. Polymerization and Formation of Colloidal Particles	135
8. Hydrolysis of Zn^{2+}	137
8.1. Polymerization and Formation of Colloidal Particles	140
9. Hydrolysis of Ga^{3+}	141
9.1. Polymerization and Formation of Colloidal Particles	141
C. Small Particles by Hydrolysis of Metal Alkoxides	143
D. Small Particles of Metal Sulfides	150
Chapter 4. Clays and Colloidal Silicas	155
Introduction	155
1. Structure - Classification	156
1.1. Structure of Kaolin and Halloysite	158
1.2. Structure of Montmorillonite	159
1.3. Structure of Attapulgite	160

2. Isomorphous Substitution - Ion Exchange Capacity	162
3. Particle Size, Shape, and Surface Area	163
4. Surface Charge	166
5. Particle Association: Flocculation and Aggregation	167
6. Peptization: Deflocculation - Dispersion	168
7. Thermal Reactions: Dehydration and Transformation	171
8. Synthetic Hectorites	173
9. Pillared Interlayered Clays - Crosslinked Smectites	173
10. Uses of Clays	175
Chapter 5. Zeolites	185
Introduction	186
A. Conventional Zeolites	187
1. Structure and Properties	187
2. Zeolites and Molecular Sieves	189
3. Properties and Applications of Zeolites	191
3.1. Ion Exchange	191
3.2. Adsorption	192
3.3. Catalysis	200
4. The Synthesis of Conventional Zeolites	206
4.1. Synthesis from Sodium Aluminosilicate Hydrogels	207
4.2. The Seeding Technique	208
4.3. Clear Homogeneous Sodium Aluminosilicate Solutions	209
4.4. Zeolite Synthesis in the Presence of Organic Cations	210
4.5. The Effect of Temperature on Crystal Size	212
4.6. The Effect of the Silica Source on the Crystal Size	212
4.7. The Effect of Additives on Crystal Size	212
4.8. Summary	213
B. Colloidal Zeolites	214
1. Synthesis of Colloidal Zeolites	214
1.1. Zeolite N-Y and N-A	214
1.2. Zeolite TPA-silicalite-1	216
1.3. Zeolite (Na, TPA)-ZSM-5	216
2. Properties of Colloidal Zeolites	218
2.1. Colloidal Zeolites <i>vis à vis</i> other Colloidal Metal Oxides and Conventional Zeolites	219
2.2. What Is meant by a "Clear Homogeneous Solution"	220
2.3. Linear Growth Rates	221
2.4. The Stability of Colloidal Zeolites	223
2.5. The Relationship Between Nucleation, Number of Crystals and Crystal Size	226
2.6. Crystal Size Tailoring of Colloidal Zeolites	227
2.7. Colloidal Zeolite Organosols	228
Chapter 6. Surfaces of Small Particles	235
A. Stability of Colloidal Dispersions	237

1. Colloid Stability	237
2. Steric Stabilization - Steric Repulsion	240
3. Electrostatic Stabilization - Electrostatic Forces	240
3.1. Electrostatic Interactions in Colloidal Systems	242
3.2. Stern Potential and Zeta Potential	244
3.3. Debye Length and Ionic Strength	245
3.4. Zeta Potential and Surface Charge Density from Electrostatic Measurements	245
B. The Surface of Small Particles in Aqueous Solutions	249
1. Coordination Chemistry at the Hydrous Metal Oxide-Water Interface	249
2. Acid-Base Characteristics of the Hydrous Metal Oxide Surface	253
3. Adsorption of Metal Ions on the Hydrous Metal Oxide Surface	254
4. Adsorption of Anions on the Hydrous Metal Oxide Surface	256
5. Isoelectric Point, i. e. p., and point of Zero-charge, p. z. c.	257
5.1. Factors Affecting i. e. p. and p. z. c.	258
5.2. Electrophoretic Mobility as a Function of pH	260
6. Surface Properties of Metal Sulfides in Aqueous Solutions	263
C. The Surface of Silica	265
1. Properties and Characteristics of the Silica Surface	266
1.1. Types of Surface Hydroxyl Groups	266
1.2. Concentration of Silanol Groups	268
1.3. Dehydration of the Silica Surface	270
1.4. Rehydroxylation of the Silica Surface	271
1.5. Stability of Colloidal Silica	272
2. Modification of the Silica Surface	275
2.1. Introduction of Aluminosilicate Sites	276
2.2. Charge Reversal	279
2.3. Nonionic Reactions of the Silica Surface	280
2.4. Organic Molecules Hydrogen Bonded to the Silica Surface	283
D. Coating of Metal Oxide Surfaces	288
1. Coating of Non-silica Surfaces with Silica	288
1.1. General Principles	288
1.2. Cores	289
1.3. The Skin	290
1.4. Rate of Deposition of Monomeric Silica	290
1.5. Coating of α -alumina with Silica	291
1.6. Coating of Titania with Silica	292
2. Non-silica Coatings on Various Cores	294
2.1. General Principles	295
2.2. Silica Particles Coated with Titania	295
2.3. Composite Particles Coated with Hydrous Metal Oxides	297
2.4. Coating Cores with Aluminum Silicate	300
E. Adsorption of Polymers on the Surface of Silica and Certain Other Surfaces	301
1. Definitions and Abbreviations	302

2. Polymers in General	303
3. Adsorption of Polymers on Silica	304
3.1. Interaction between Silica and Non-ionic Polymers, $\tau=0$	305
3.2. Comparison between Interactions of Nonionic and Cationic Polymers with Silica	308
3.3. Interaction between Silica and Cationic Polymers	315
4. Summary and Conclusions	323
 Chapter 7. Catalyst Supports and Small Particle Catalysts	 327
Introduction	328
1. Structure of Catalysts	329
2. Catalysts with Supports on Carriers - Catalysts for Pollution Control	330
2.1. Monolithic Carriers	331
2.2. Fibrous Carriers	332
2.3. Structure of Washcoats of Silica and Alumina on Carriers	336
2.4. Catalysts with Supports of Alumina and Silica on Carriers	342
3. Catalysts for Hydroprocessing of Oil	351
3.1. Hydrotreatment Catalysts with Different Pore Structures	352
4. Fluid Catalytic Cracking Catalysts, FCCC	354
4.1 Zeolites	355
4.2. Matrices	357
4.3. Octane-enhancing Catalysts	361
4.4. Catalysts for Cracking Heavy Oils	361
5. Catalysts for the Chemical Industry	364
 Chapter 8. Pigments	 369
1. Classification	370
2. Economic Aspects	370
3. Properties	371
3.1. Chemical Properties	371
3.2. Physical Properties	372
3.3. Optical Properties	375
3.4. Light, Weather, and Heat Stability	378
3.5. Comparison between the Properties of Organic and Inorganic Pigments	379
4. White Pigments	379
4.1. Titanium Dioxide	380
4.2. Zinc Oxide	383
4.3. Zinc Sulfide and Lithopone	383
5. Extender Pigments	384
6. Black Pigments	384
6.1. Properties	384
6.2. Formation Mechanisms	387
6.3. Manufacture	387
6.4. Uses	388
7. Colored Pigments	390
7.1. Inorganic Colored Pigments	390
7.2. Organic Colored Pigments	395

8. Specialty Pigments	400
8.1. Magnetic Pigments	400
8.2. Luster Pigments	401
8.3. Transparent Pigments	403
Chapter 9. Small Particles in Paper	407
1. Paper and Paper Board	407
2. Fillers	407
2.1. Types of Fillers	408
2.2. Pigments	408
3. Papermaking	410
The Problem	411
4. Retention	413
Retention Mechanisms	413
5. Retention Aids	418
Dual Retention Aid Systems	420
Chapter 10. Various Applications of Small Particles	431
A. Functions	433
1. Adsorbency	433
1.1. Adsorbents-Silica Gels and Powders	434
2. Thickening, Suspensions, and Viscosity Control	447
2.1. General Considerations	448
2.2. Effect of pH and Charge on Viscosity	449
2.3. Effect of Particle Shape on Viscosity	452
2.4. Effect of Salt on Viscosity	455
2.5. Thickening Effect of Small Particles	455
3. Bonding and Reinforcing	458
3.1. Mechanism of Film Formation	458
3.2. Small Particles as Binders in Mats and Felts	460
3.3. Small Particles as Binders for Spherical and Rounded Particles	461
4. Anchoring Agents, Mordants, Surface Modifiers	463
B. Applications	464
1. Ceramics	464
1.1. Definition	465
1.2. Classification	466
1.3. Advanced Ceramics	469
2. Coatings	478
2.1. Ceramic Coatings	479
2.2. Other Coatings	481
3. Paints, Lacquers, and Printing Inks	482
3.1. Components	482
3.2 Applications - Products	491
4. Fillers in Plastics	495
4.1. Types of Fillers	495

4.2. Filler Particle Properties and Their Effect on Resin Properties	497
4.3. Modifying the Filler Particle Surface - Coupling Agents	501
4.4. Effect of Filler Particle Size on Mechanical Properties	503
5. Textiles	506
5.1. Treatment with Alkali Silicates	507
5.2. Treatment with Silica Sols	507
5.3. Treatment with Alumina Particles	508
6. Particle Strengthening of Metals and Alloys	511
7. Small Particle Contamination	512
Particle-Surface Adhesion	513
Subject Index	519