

Contents

Preface — V

Chapter 1

Overview and introduction — 1

- 1.1 Introduction and history: the roots of materials science — 1
- 1.2 New materials as the periodic table was formed — 2
- 1.3 The materials chemistry explosion, post-Second World War — 5
- 1.4 Recycling — 6
- References — 9

Chapter 2

Basic principles of materials chemistry — 13

- 2.1 Solid-state materials — 13
 - 2.1.1 Metals and alloys — 13
 - 2.1.2 Ceramics and glasses — 15
 - 2.1.3 Plastics — 17
- 2.2 Nonsolid phases of matter — 18
 - 2.2.1 Ionic liquids — 18
 - 2.2.2 Ferrofluids — 19
 - 2.2.3 Novel gases – and their uses — 19
- 2.3 Recycling or downcycling — 21
- References — 23

Chapter 3

Synthetic chemistry — 25

- 3.1 The search for novel materials — 25
- 3.2 Organic synthesis — 26
 - 3.2.1 Polymers — 27
 - 3.2.2 Organic synthesis and the carbon–halide bond — 29
 - 3.2.3 Organic synthesis and the double bond — 30
- 3.3 Inorganic syntheses — 31
 - 3.3.1 Metals — 31
 - 3.3.2 Ceramics — 34
- 3.4 Hard materials – the need by NASA — 36
 - 3.4.1 Materials critical to the space aerospace industry — 36
 - 3.4.2 Diamond — 37
 - 3.4.3 Nitrides and carbides — 38
- References — 38

Chapter 4

Chemical bonding — 39

- 4.1 Ionic and molecular bonding — **39**
 - 4.1.1 Ionic nature — **41**
 - 4.1.2 Covalent nature — **41**
 - 4.1.3 The dative bond or coordinate covalent bond — **43**
- 4.2 Metallic bonding — **44**
- 4.3 Secondary bonding, intermolecular forces — **49**
 - 4.3.1 Hydrogen bonding — **49**
 - 4.3.2 Dipole interactions — **51**
 - 4.3.3 London forces — **53**
- References — **54**

Chapter 5

Structure of matter — 55

- 5.1 Crystalline solids — **55**
- 5.2 Unit cells and crystals — **56**
- 5.3 Packing of particles — **57**
- 5.4 Holes in crystal structures — **60**
- 5.5 Amorphous materials — **61**
- 5.6 Semisolids — **62**
- 5.7 Crystalline or noncrystalline metallic solids — **63**
 - 5.7.1 Mercury and gallium — **63**
 - 5.7.2 Tin scream — **63**
 - 5.7.3 Metal foams — **64**
- 5.8 Recycling — **64**
- References — **65**

Chapter 6

Molecules — 67

- 6.1 Introduction — **67**
- 6.2 Organic molecular materials — **67**
 - 6.2.1 Fully covalent molecules — **67**
 - 6.2.2 The organic–inorganic matter borderline — **69**
 - 6.2.3 Waxes — **70**
 - 6.2.4 Polymers — **72**
- 6.3 Carbon dioxide — **72**
- 6.4 Inorganic molecules and compounds — **74**
 - 6.4.1 Sulfur and sulfur crowns — **74**
 - 6.4.2 Sulfuric acid production — **75**
 - 6.4.3 Iodine, I_2 — **76**
 - 6.4.4 Chlorine — **76**

- 6.4.5 Interhalogen compounds — 76
- 6.4.6 Allotropes of phosphorus — 77
- 6.4.7 UF_6 — 78
- 6.4.8 SF_6 — 79
- 6.5 Hybrids, metal-organic frameworks — 79
- 6.6 Recycling possibilities — 80
- References — 81

Chapter 7

Polymers — 83

- 7.1 Introduction and history — 83
- 7.1.1 Nylon – as a replacement for silk — 84
- 7.1.2 Synthetic rubber – starting with 1,3-butadiene — 84
- 7.1.3 Naugahyde – PVC-coated knit fiber, as artificial leather — 85
- 7.1.4 Polytetrafluoroethylene (PTFE) – generally called Teflon — 85
- 7.2 Petroleum-based polymers — 86
- 7.2.1 Other petroleum-based polymers — 89
- 7.2.2 Plasticizers — 91
- 7.2.3 Recycling of petroleum-based polymers — 91
- 7.3 Renewable and nonpetroleum-based polymers — 92
- 7.3.1 Polylactic acid (PLA) — 93
- 7.3.2 Polyhydroxyalkanoates (PHAs) — 93
- 7.3.3 Silicones — 94
- 7.3.4 Recycling, silicon-based polymers — 95
- 7.4 Polymer composites — 96
- 7.5 Thermoset polymers — 97
- 7.6 Thermoplastic polymers — 98
- 7.7 Recycling — 99
- References — 100

Chapter 8

Metals and metallurgy — 103

- 8.1 Introduction — 103
- 8.2 Elemental metals — 103
- 8.2.1 Metals from antiquity — 103
- 8.2.2 Iron — 105
- 8.2.3 Silver — 113
- 8.2.4 Gold — 115
- 8.2.5 Copper — 122
- 8.2.6 Aluminum – Hall–Heroult process — 128
- 8.2.7 Titanium – Kroll process — 131
- 8.2.8 Platinum group metals or precious metals — 134

8.3	High-performance element and alloys —	141
8.3.1	Titanium —	141
8.3.2	Tungsten —	141
8.3.3	Magnesium —	142
8.3.4	Aluminum —	146
8.4	The discoveries of the 1700s and 1800s —	146
8.4.1	Lanthanides —	146
8.5	Ferrous-based alloys —	154
8.6	Other metal alloys —	155
8.6.1	Low melting alloys —	155
8.6.2	Lanthanide-containing alloys and others —	156
8.7	Novel metal architectures (e.g., foams) —	158
8.8	Magnetic materials —	159
8.9	ASTM standards for metals —	160
8.10	Recycling —	160
	References —	161

Chapter 9

Defect structures — 165

9.1	Introduction —	165
9.2	Intrinsic point defects —	166
9.2.1	Frenkel defects – aka, interstitial defects —	166
9.2.2	Schottky defects – aka, vacancy defects —	167
9.3	Extrinsic point defects —	168
9.4	Extended defects —	170
	References —	171

Chapter 10

Conductors — 173

10.1	Introduction of metal-based conductors —	173
10.2	Nonmetal elements and conductivity —	174
10.3	Organic conductors —	174
10.3.1	Doped polyacetylene —	176
10.3.2	Poly(<i>p</i> -phenylene vinylene) —	176
10.3.3	Conductive metal-organic frameworks (MOFs) —	176
	References —	178

Chapter 11

Semiconductors — 179

11.1	Introduction —	179
11.2	Silicon —	181
11.3	Germanium —	182

- 11.4 Gallium arsenide — **183**
- 11.5 Other non-silicon-based semiconductors — **184**
- 11.5.1 Metal oxide semiconductors — **184**
- 11.5.2 Semiconducting polymers — **186**
- 11.6 Recycling — **187**
- References — **188**

Chapter 12

Superconductors — 189

- 12.1 Introduction — **189**
- 12.2 Known elemental superconductors — **189**
- 12.3 Temperature correlations — **192**
- 12.4 Potential superconductors — **195**
- 12.5 Goals for superconducting materials — **195**
- References — **196**

Chapter 13

Biomaterials — 197

- 13.1 Introduction — **197**
- 13.2 Materials for medical use — **197**
- 13.2.1 Bone mimics — **198**
- 13.2.2 Contact lenses — **198**
- 13.2.3 Body parts — **199**
- 13.2.4 Hernia mesh — **200**
- 13.2.5 Skin grafting and repair — **203**
- 13.2.6 Silk — **203**
- 13.3 Mycelium-based end-user items — **204**
- 13.4 Biofuels — **205**
- 13.5 Bioplastics — **206**
- 13.5.1 Polylactic acid — **207**
- 13.5.2 Polyethylene — **207**
- 13.5.3 Polyhydroxybutyrate — **208**
- 13.5.4 Cellulose — **208**
- 13.5.5 Polycaprolactone — **208**
- 13.6 Biomaterials for nonmedical applications — **209**
- References — **209**

Chapter 14

Ceramics — 211

- 14.1 Introduction, history, basic compositions — **211**
- 14.2 Ceramic production and properties — **213**
- 14.3 Major uses of ceramics — **216**

- 14.3.1 Roofing tile — **216**
- 14.3.2 Floor tile — **216**
- 14.3.3 Wall tiling and facing, brick work — **218**
- 14.3.4 Tableware and cookware — **218**
- 14.3.5 Kiln and oven linings — **220**
- 14.3.6 Ballistic body armor inserts — **220**
- 14.3.7 Armored vehicle plating and reinforcement — **221**
- References — **221**

Chapter 15

Glasses — 223

- 15.1 Introduction and history — **223**
- 15.2 Basic compositions — **224**
- 15.3 Glass blowing and the Pilkington process — **227**
- 15.4 Optical cabling — **228**
- 15.5 Bullet-proof glass — **229**
- 15.6 Additives and optical properties — **230**
- 15.7 Uses of types of glass — **233**
- 15.8 Glass recycling — **233**
- References — **234**

Chapter 16

Cement and concrete — 235

- 16.1 Introduction and history — **235**
- 16.2 Geographic sources — **235**
- 16.3 Cement formulation chemistry — **237**
- 16.3.1 Hydraulic cement: reaction chemistry — **237**
- 16.3.2 Chemistry: nonhydraulic cements — **238**
- 16.3.3 Cement: other types — **239**
- 16.4 Cement and concrete: major uses — **241**
- 16.5 Cement recycling — **241**
- References — **242**

Chapter 17

Lightweight materials — 245

- 17.1 Introduction — **245**
- 17.2 Basic classifications — **245**
- 17.2.1 Metal materials — **247**
- 17.2.2 Ceramic materials — **248**
- 17.3 Polymers and plastics — **249**
- 17.4 Recycling — **250**
- References — **251**

Chapter 18**Hard materials — 253**

- 18.1 Introduction — **253**
- 18.2 Basic classifications — **256**
 - 18.2.1 Natural diamond — **256**
 - 18.2.2 Diamond and silicon carbide — **257**
 - 18.2.3 Ceramic materials — **259**
 - 18.2.4 Metal materials, carbides — **259**
 - 18.2.5 Boron nitrides — **260**
 - 18.2.6 Metal borides — **261**
- 18.3 Recycling — **261**
 - References — **262**

Index — 263

