

# Contents

<b>1</b>	<b>Introduction</b>	<b>11</b>
<b>2</b>	<b>Properties of Copper</b>	<b>13</b>
2.1	Copper as an Element in the Periodic Table . . . . .	13
2.2	Physical Properties . . . . .	16
2.2.1	Mechanical Properties . . . . .	16
2.2.2	Electrical Properties . . . . .	19
2.2.3	Thermal Properties . . . . .	22
2.3	Chemical Properties . . . . .	24
2.3.1	Copper in the Electromotive Force Series (e.m.f. series )	24
2.3.2	Behavior of Copper in Water and Aqueous Solutions . .	27
2.3.2.1	Behavior in Air and Water . . . . .	27
2.3.2.2	Dissolution in Acids . . . . .	29
2.3.3	Reactions with Gases . . . . .	30
2.3.4	Complex Compounds . . . . .	31
2.4	Biological Role of Copper . . . . .	34
2.4.1	Copper - the Essential Trace Element . . . . .	34
2.4.2	Copper Toxicity . . . . .	35
2.4.3	Antimicrobial Properties of Copper . . . . .	36
<b>3</b>	<b>History of Copper</b>	<b>39</b>
<b>4</b>	<b>Occurrence of Copper</b>	<b>47</b>
4.1	Copper Minerals . . . . .	48
4.1.1	Primary (Hypogene) Minerals . . . . .	48
4.1.2	Secondary Minerals . . . . .	50
4.1.3	Secondary Sulfides . . . . .	52
4.1.4	Mineral Structure of a Copper Deposit . . . . .	52
4.1.5	Copper Minerals in the World . . . . .	53
4.1.6	Reserves and Resources of Copper Minerals . . . . .	55
<b>5</b>	<b>Primary Production of Copper</b>	<b>57</b>
5.1	Mining . . . . .	57
5.1.1	Exploration of a Copper Mine . . . . .	57

5.1.2	Production of Copper Concentrates . . . . .	59
5.1.3	Environmental Aspects of Mining . . . . .	65
5.1.4	The Biggest Copper Mines in the world . . . . .	70
5.1.5	Biggest Copper Mining Companies . . . . .	82
5.1.6	Cost Structure of Copper Concentrate Production . . . . .	84
5.1.7	Marketing Copper Concentrates . . . . .	87
5.2	Hydrometallurgical Extraction of Copper . . . . .	91
5.2.1	Heap Leaching . . . . .	92
5.2.2	Dump Leaching . . . . .	96
5.2.3	In Situ Leaching . . . . .	96
5.2.4	Solventextraction and Electrowinning (SX/EW) . . . . .	97
5.2.5	The Flowsheet of Hydrometallurgical Copper Extraction . . . . .	99
5.2.6	The biggest Copper Leaching Operations . . . . .	100
5.2.7	Economics of SX-EW Copper Production . . . . .	101
5.3	Production of Copper Cathodes from Sulfidic Ores . . . . .	103
5.3.1	Sampling and Analytics of Concentrates . . . . .	103
5.3.1.1	Sampling . . . . .	103
5.3.1.2	Analytics . . . . .	105
5.3.2	Basics of Smelting and Refining . . . . .	107
5.3.3	Smelting . . . . .	109
5.3.3.1	Reverberatory Furnace . . . . .	111
5.3.3.2	Outokumpu (Outotec) Flash Smelting . . . . .	112
5.3.3.3	Inco Flash Smelter . . . . .	115
5.3.3.4	Noranda Process . . . . .	116
5.3.3.5	Teniente Reactor . . . . .	117
5.3.3.6	Isasmelt/Ausmelt . . . . .	118
5.3.3.7	Other Processes . . . . .	120
5.3.4	Converting Copper Matte . . . . .	121
5.3.4.1	Peirce Smith Converter . . . . .	122
5.3.4.2	Hoboken Converter . . . . .	124
5.3.4.3	Mitsubishi™process . . . . .	126
5.3.5	Direct Copper smelting . . . . .	128
5.3.6	Anode Casting . . . . .	129
5.3.7	By-Products of Smelting: Slag Treatment . . . . .	133
5.3.8	By-Products of Smelting and Converting: Sulfuric Acid . . . . .	136
5.3.8.1	Sulfuric Acid Market . . . . .	142
5.3.9	Electrolytic Refining . . . . .	145
5.3.9.1	Basic Principles . . . . .	146
5.3.9.2	Conditions of Electrorefining . . . . .	148
5.3.9.3	Tankhouse Operations . . . . .	150
5.3.9.4	Treatment of the Bleed off of the Tankhouse . . . . .	153
5.3.9.5	Treatment of the Anode Slime . . . . .	156

5.3.10	Environmental Effects of Smelting and Refining . . . . .	158
5.3.10.1	Emissions to the Air . . . . .	159
5.3.10.2	Waste Water . . . . .	161
5.3.10.3	Waste . . . . .	162
5.3.11	Energy consumption of Smelting and Refining . . . . .	163
5.3.12	The biggest Smelters and Refiners . . . . .	165
5.3.13	Economy of Smelting and Refining . . . . .	167
5.3.14	Leaching of Concentrates . . . . .	168
5.3.14.1	Hydrocopper™ process . . . . .	170
5.3.14.2	CESL™ process . . . . .	170
5.3.14.3	Freeport High Temperature (HT) leach . . . . .	170
5.3.14.4	Albion Process . . . . .	172
5.3.14.5	Other Processes . . . . .	172
5.3.15	Outlook . . . . .	172
<b>6</b>	<b>Recycling (Secondary Production of Copper)</b>	<b>175</b>
6.1	Types of Scrap . . . . .	177
6.1.1	Production Scrap (New Scrap) . . . . .	177
6.1.2	Old Scrap . . . . .	180
6.1.2.1	Cable Scrap . . . . .	181
6.1.2.2	Old Copper and Copper Alloy Scrap . . . . .	183
6.1.3	Special Copper Scraps . . . . .	185
6.1.3.1	Electronic Scrap . . . . .	185
6.1.3.2	Scrapped Cars . . . . .	187
6.1.4	Residues . . . . .	188
6.2	Processing of Scrap . . . . .	188
6.2.1	Direct Melting . . . . .	188
6.2.2	Smelting and Refining . . . . .	189
6.3	Environmental Aspects and Energy Consumption . . . . .	198
6.4	The Biggest Copper Recycling Companies . . . . .	199
6.5	Economics . . . . .	199
6.6	Outlook . . . . .	202
<b>7</b>	<b>The Copper Cathode - Base of the Copper Business</b>	<b>203</b>
7.1	Quality . . . . .	204
7.2	The biggest Copper Cathode Producers . . . . .	205
7.3	LME . . . . .	205
7.3.1	Registration . . . . .	208
7.3.2	Trading . . . . .	208
7.3.3	Hedging . . . . .	209
7.3.4	Other Metal Exchanges . . . . .	211
7.3.4.1	CME Group (Comex) . . . . .	211

7.3.4.2	Shanghai Future Exchange . . . . .	212
7.4	Pricing of Copper and Copper Products . . . . .	212
7.4.1	Copper Cathode Premium . . . . .	213
7.4.2	Other Copper Quotations . . . . .	214
7.5	Global Trade of Copper Cathodes . . . . .	214
<b>8</b>	<b>Production of Copper Products</b>	<b>217</b>
8.1	First Use of Copper Cathodes . . . . .	218
8.1.1	Copper Species . . . . .	219
8.1.1.1	ETP-Copper (Cu-ETP) UNS: C110 . . . . .	219
8.1.1.2	Oxygen-Free Copper (Cu-OFE and Cu-OF) UNS- No -Group. C101, C102 . . . . .	222
8.1.1.3	Phosphorous Deoxidized Copper (Cu-PHC, Cu- HCP, Cu-OF-XLP, SE-Copper) UNS-No -Group. C103 . . . . .	223
8.1.1.4	Phosphorus Containing Copper (DHP-Copper, DLP-Copper) UNS-No -Group. C12x . . . . .	224
8.1.1.5	Low alloyed Copper UNS-No-Group: C1x . . . . .	224
8.1.2	Copper Wire Rod . . . . .	225
8.1.2.1	The biggest Rod Producers . . . . .	228
8.1.2.2	Production . . . . .	230
8.1.2.3	Economics of wire rod production . . . . .	235
8.1.3	Copper Shapes: Billets and Cakes (Slabs) . . . . .	236
8.1.3.1	Continuous Casting of Shapes . . . . .	237
8.1.3.2	Strip Casting . . . . .	239
8.1.3.3	Conti-M . . . . .	239
8.1.3.4	Cast&Roll® . . . . .	240
8.1.3.5	Economics of Casting Billets and Cakes . . . . .	240
8.1.4	Copper Powder . . . . .	241
8.1.4.1	Reduction of Copper Oxides . . . . .	241
8.1.4.2	Atomizing . . . . .	242
8.1.4.3	Copper Flakes . . . . .	243
8.1.4.4	Economics of copper powder . . . . .	243
8.2	Copper Alloys . . . . .	243
8.2.1	Production of Copper Alloys . . . . .	246
8.2.2	Brass . . . . .	248
8.2.3	Bronze . . . . .	252
8.2.4	Special Bronzes . . . . .	254
8.2.5	Nickel Silver . . . . .	256
8.2.6	High Performance Alloys (HPA) . . . . .	256
8.2.7	Nordic Gold™ . . . . .	260

8.3	Production and Applications of Copper Semi-Products . . . .	262
8.3.1	Production and Applications of Wires . . . . .	262
8.3.1.1	Bare wires . . . . .	263
8.3.1.2	Magnet Wires . . . . .	264
8.3.1.3	Trolley Wire . . . . .	265
8.3.1.4	EDM wires . . . . .	265
8.3.1.5	Applications of Wires . . . . .	266
8.3.1.6	Copper or Aluminum? . . . . .	267
8.3.2	Production and Applications of Strips and Plates . . . .	270
8.3.2.1	Production of Strips . . . . .	270
8.3.2.2	Applications of Copper Strip . . . . .	274
8.3.3	Production and Application of Tubes . . . . .	281
8.3.3.1	Production of Tubes . . . . .	283
8.3.3.2	Applications of Copper Tubes . . . . .	284
8.3.4	Production of Profiles, Bars and Rod . . . . .	288
8.3.5	Production and Applications of Forgings . . . . .	291
8.3.6	Economy of Semis Production . . . . .	291
8.3.7	The biggest Cable and Wire Producers . . . . .	295
8.3.8	The Biggest Semis Producers . . . . .	297
8.4	Copper Chemicals . . . . .	301
8.4.1	Copper chemicals in wood preservation . . . . .	302
8.4.2	Antifouling paints . . . . .	303
8.4.3	Copper Chemicals in Agriculture . . . . .	304
8.4.4	Copper Chemicals in Electroplating . . . . .	305
8.4.5	Other Applications of Copper Chemicals . . . . .	306
<b>9</b>	<b>Copper and Copper Alloys in final Industrial and OEM Applications</b>	<b>309</b>
9.1	Applications based on the Electrical Conductivity of copper . .	309
9.1.1	Copper in Power generation . . . . .	310
9.1.1.1	Electrical Power Turbines . . . . .	310
9.1.1.2	Electrical Power from Wind Energy . . . . .	311
9.1.1.3	Electrical Power from Photovoltaic Energy . .	312
9.1.2	Transformers . . . . .	314
9.1.3	Electrical Motors . . . . .	315
9.1.3.1	Copper in Cars and Trucks . . . . .	317
9.1.3.2	Copper in other Transportation Industries . .	318
9.2	Applications based on Thermal Conductivity . . . . .	319
9.2.1	Copper Tubes in ACR . . . . .	319
9.2.2	Cooling in Metallurgy . . . . .	319
9.2.3	Solar Thermal Energy . . . . .	320
9.3	Copper in Buildings . . . . .	323

<b>10 Economics from Copper Ore to Final Application</b>	<b>325</b>
10.1 The Value Chain of Copper . . . . .	325
10.1.1 Revenues in the Value Chain of Copper . . . . .	325
10.1.2 Yield of Copper and Scrap Rates in the Value Chain of Copper . . . . .	329
10.2 The Role of Copper Prices . . . . .	332
10.2.1 Substitution of Copper . . . . .	334
10.2.2 Financing of Copper - Working Capital in the Value Chain of Copper . . . . .	335
10.2.3 Risk of Copper Price Changes . . . . .	338
10.3 Energy Consumption in the Value Chain of Copper . . . . .	340
<b>11 Outlook for the Copper Industry</b>	<b>343</b>
<b>12 Appendix (Tables)</b>	<b>347</b>
12.1 Copper Companies . . . . .	347
12.1.1 Copper Mines . . . . .	347
12.1.2 Copper Smelters and Refiners . . . . .	354
12.1.3 Semi Producers . . . . .	361
12.2 Copper related Organizations . . . . .	368
12.2.1 Copper Development Associations (CDA) . . . . .	368
12.2.2 Copper Studies . . . . .	369
12.3 Literature . . . . .	370