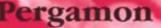
## EXTRACTIVE METALLURGY OF COPPER

fourth edition

W.G. DAVENPORT M. KING M. SCHLESINGER A.K. BISWAS



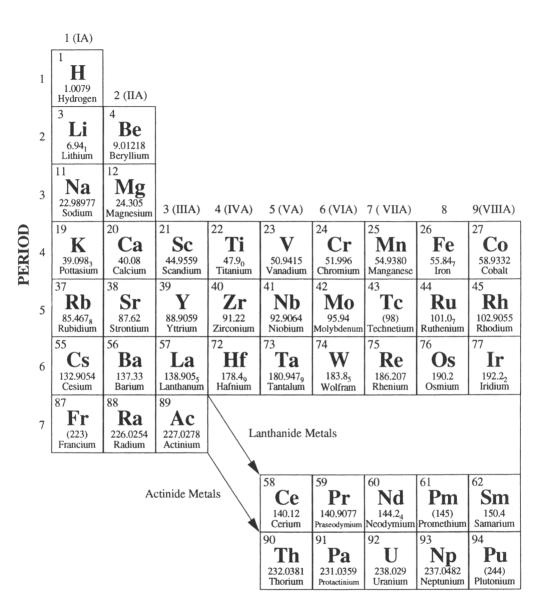












								18 (VIIIB)
								2
								He
			13 (IIIB)	14 (IVB)	15 (VB)	16 (VIB)	17 (VIIB)	4.00260 Helium
			5	6	7	8	9	10
			B	<b>C</b>		0	F	Ne
			10.81 Boron	12.011 Carbon	14.0067 Nitrogen	15.999 <sub>4</sub> Oxygen	18.998403 Fluorine	20.17 <sub>9</sub> Neon
			13	14	15	16	17	18
			Al	Si	P	S	Cl	Ar
10	11(IB)	12(IIB)	26.98154 Boron	28.085 <sub>5</sub> Silicon	30.97376 Phosphorous	32.06 Sulphur	35,453 Chlorine	39.94 <sub>8</sub> Argon
28	29	30	31	32	33	34	35	36
Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
58.70	63.546	65.38	69.72	72.5 <sub>9</sub>	74.9216	78.9 <sub>6</sub>	79.904	83.80
Nickel	Copper	Zinc	Gallium	Germanium	Arsenic	Selenium	Bromine	Krypton
46	47	48	49	50	51	52	53	54
Pd	Ag	Cd	In	Sn	Sb	Te	Ι	Xe
106.4 Palladium	107.868 Silver	112.41	114.82	118.69	121.75	127.60	126.9045	131.30
		Cadmium	Indium	Tin	Antimony	Tellurium	Iodine	Xenon
78	79	80	81	82	83	84	85	86
<b>Pt</b>	Au	Hg	TI	Pb	Bi	Po	At	Rn
195.09	196.9665	$200.5_9$	204.37	207.2	208.9804	(209)	(210)	(222)
Platinum	Gold	Mercury	Thallium	Lead	Bismuth	Polonium	Astatine	Radon

63	64	65	66	67	68	69	70	71
Eu	<b>Gd</b>	<b>Tb</b>	Dy	<b>Ho</b>	Er	<b>Tm</b>	<b>Yb</b>	<b>Lu</b>
151.96	157.2 <sub>5</sub>	158.9254	162.5 <sub>0</sub>	164.9304	167.2 <sub>6</sub>	168.9342	173.0 <sub>4</sub>	174.96 <sub>7</sub>
Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium
95	96	97	98	99	100	101	102	103
Am	<b>Cm</b>	Bk	Cf	Es	Fm	Md	No	Lr
(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(260)
Americium	Curium	Berkelium	Californium	Einsteintium	Fermium	Mendelevium	Nobelium	Lawrencium

# Extractive Metallurgy of Copper

FOURTH EDITION

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## Extractive Metallurgy of Copper

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FOURTH EDITION



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## Preface

This edition contains more-than-ever industrial information, all of it provided generously by our industrial friends and colleagues. We thank them profusely for their help and generosity over the years.

The publication we consulted most for this edition was *Copper 99/Cobre99* (TMS, Warrendale, PA [six volumes]). For a near-future update, we direct the reader to *Copper 03/Cobre 03* being held in Santiago, Chile, November 30, 2003 (www.cu2003.cl).

As with previous editions, Margaret Davenport read every word of our manuscript. After 27 years of proofreading, she may well know more than the authors.

## Dedication

It is with great sadness that we report the death of Anil Biswas – friend, colleague and inspiration. Co-author of all previous editions, Anil was at the Department of Mining and Metallurgical Engineering, University of Queensland, St Lucia, Brisbane, Australia.

Anil's objectives for this book were to (i) describe how copper metal is extracted from ore and scrap, and (ii) indicate how the extraction could be made more efficient. We are proud to continue with his original plan.

March 31, 2002

W.G. Davenport, Cambridge, England M.J. King, Phoenix, Arizona M.E. Schlesinger, Rolla, Missouri

## **Preface to the Third Edition**

This edition chronicles the changes which have taken place in copper extraction over the last 20 years. The major changes have been the shrinkage of reverberatory smelting, the continued growth of flash smelting and the remarkable (and continuing) growth of solvent extraction/electrowinning. The use of stainless steel cathodes (instead of copper starting sheets) in electrorefining and electrowinning has also been a significant development.

These industrial growth areas receive considerable attention in this edition as do  $SO_2$  collection and sulphuric acid manufacture.  $SO_2$  capture has continued to grow in importance – only a few smelters now emit their  $SO_2$  to the atmosphere.

Several important volumes on copper extraction have appeared recently, namely: *Copper 91/Cobre 91* (Pergamon Press, New York [four volumes]) and *Extractive Metallurgy of Copper, Nickel and Cobolt* (TMS, Warrendale, Pennsylvania [two volumes]). A volume on *Converting, Fire-refining and Casting* is scheduled to appear in 1994 (TMS) and the proceedings of *Cobre95/Copper 95* will appear in 1995. The reader is directed to these publications for updated information.

We wish to thank our colleagues in the copper industry for their many contributions to this edition. They have responded to our questions, encouraged us to visit their plants and engaged us in rigorous debate regarding extraction optimization. We would particularly like to thank Brian Felske (Felske and Associates), David Jones (Magma Copper Company) and Eric Partelpoeg (Phelps Dodge Mining Company). Without them this edition would not have been possible.

The manuscript was prepared and proofed by Patricia Davenport and Margaret Davenport. Their perseverance, skill and enthusiasm are happily acknowledged.

### Preface to the Second Edition

For this edition we have concentrated mainly on bringing the operating data and process descriptions of the first edition up to date. Typographical errors have been corrected and several passages have been rewritten to avoid misinterpretation. Since most of the new data have come directly from operating plants, very few new references have been added. For collections of recent published information, the reader is directed to the excellent symposium publications: Extractive Metallurgy of Copper, Volumes I and II, Yannopoulos, J. C. and Agarwal, J. C. editors, A.I.M.E., New York, 1976, Copper and Nickel Converters, Johnson, R.E., A.I.M.E., New York, 1979, and to the reviews of copper technology and extractive metallurgy published annually in the Journal of Metals (A.I.M.E., New York). Most of the credit for this edition should go to the many industrial engineers and scientists who almost without exception responded to our requests for new information on their processes. We would like in particular to single out Jan Matousek of INCO. Keith Murden of Outokumpu Oy and John Schloen of Canadian Copper Refiners (now a metallurgical consultant) for their help.

September 1979

A. K. Biswas W. G. Davenport

## **Preface to the First Edition**

This book describes the extraction of copper from its ores. The starting point is with copper ores and minerals and the finishing point is the casting and quality control of electrical grade copper. Techniques for recovering copper from recycled scrap are also discussed.

The main objectives of the book are to describe the extractive metallurgy of copper as it is today and to discuss (qualitatively and quantitatively) the reasons for using each particular process. Arising from these descriptions and discussions are indications as to how copper-extraction methods will develop in the future. Control of air and water pollution is of tremendous importance when considering future developments and these are discussed in detail for each process. Likewise, the energy demands of each process are dealt with in detail. Costs are mentioned throughout the text and they are considered in depth in the final chapter.

The book begins with an introductory synopsis (for the generalist reader) of the major copper-extraction processes. It then follows copper extraction in a stepwise fashion beginning with mineral benefication and advancing through roasting, smelting, converting, refining, casting and quality control. Hydrometallurgy and its associated processes are introduced just before electrorefining so that electrowinning and electrorefining can be discussed side by side and the final products of each method compared. The last two chapters are not in sequence – they are devoted to the sulphur pollution problem and to economics.

As far as possible, the length of each chapter is commensurate with the relative importance of the process it describes. Blast-furnace copper smelting is, for example, given a rather brief treatment because it is a dying process while newer techniques such a continuous copper-making and solvent extraction are given extensive coverage because they may assume considerable importance in the near future.

A word about units: the book is metric throughout, the only major exception to the Standard International Unit System being that energy is reported in terms of kilocalories and kilowatt-hours. The principal units of the book are metric tons (always written tonnes in the text), kilograms and metres. A conversion table is provided in Appendix I. A knowledge of thermodynamics is assumed in parts of the book, particularly with respect to equilibrium constants. For concise information on the thermodynamic method as applied to metallurgy, the reader is