

The background of the cover features a close-up, high-contrast photograph of copper coils, showing their metallic texture and the way they are stacked and curved.

EXTRACTIVE METALLURGY OF COPPER

fourth edition

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

Pergamon

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PERIOD	1 (IA)																
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	37	38	39	40	41	42	43	44	45								
	55	56	57	72	73	74	75	76	77								
	87	88	89	Lanthanide Metals													
			Actinide Metals														
	58	59	60	61	62												
	90	91	92	93	94												

										18 (VIII B)
										2 He 4.00260 Helium
										13 (IIIB) 14 (IVB) 15 (VB) 16 (VIB) 17 (VIIB)
										5 B 10.81 Boron
										6 C 12.011 Carbon
										7 N 14.0067 Nitrogen
										8 O 15.999 ₄ Oxygen
										9 F 18.998403 Fluorine
										10 Ne 20.17 ₉ Neon
										13 Al 26.98154 Boron
										14 Si 28.085 ₅ Silicon
										15 P 30.97376 Phosphorous
										16 S 32.06 Sulphur
										17 Cl 35.453 Chlorine
										18 Ar 39.94 ₈ Argon
10	11 (IB)	12 (IIB)								
28 Ni 58.70 Nickel	29 Cu 63.54 ₆ Copper	30 Zn 65.38 Zinc	31 Ga 69.72 Gallium	32 Ge 72.5 ₉ Germanium	33 As 74.9216 Arsenic	34 Se 78.9 ₆ Selenium	35 Br 79.904 Bromine	36 Kr 83.80 Krypton		
46 Pd 106.4 Palladium	47 Ag 107.868 Silver	48 Cd 112.41 Cadmium	49 In 114.82 Indium	50 Sn 118.6 ₉ Tin	51 Sb 121.7 ₅ Antimony	52 Te 127.6 ₀ Tellurium	53 I 126.9045 Iodine	54 Xe 131.30 Xenon		
78 Pt 195.0 ₉ Platinum	79 Au 196.9665 Gold	80 Hg 200.5 ₉ Mercury	81 Tl 204.3 ₇ Thallium	82 Pb 207.2 Lead	83 Bi 208.9804 Bismuth	84 Po (209) Polonium	85 At (210) Astatine	86 Rn (222) Radon		

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

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Extractive Metallurgy of Copper

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Extractive Metallurgy of Copper

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FOURTH EDITION

PERGAMON



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First edition	1976
Second edition	1980
Third edition	1994
Fourth edition	2002

British Library Cataloguing in Publication Data

Davenport, W. G. (William George)
Extractive metallurgy of copper. - 4th ed.
I. Copper - Metallurgy
I. Title II. King, M. III. Schlesinger, M. IV. Biswas, A. K.
(Anil Kumar)
669.3

ISBN 0080440290

Library of Congress Cataloging in Publication Data

A catalog record from the Library of Congress has been applied for.

ISBN: 0-08-044029-0

∞ The paper used in this publication meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).
Printed in The Netherlands.

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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

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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 SO₂ collection and sulphuric acid manufacture. SO₂ capture has continued to grow in importance – only a few smelters now emit their SO₂ 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 Cobalt* (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.

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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

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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 step-wise fashion beginning with mineral beneficiation 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 as 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