

669

669  
5646  
S. W.

# Metals Reference Book

Editor

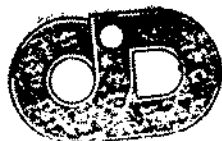
COLIN J. SMITHELLS M.C., D.Sc., F.I.M.

Assistant Editor

ERIC A. BRANDES B.Sc., A.R.C.S., F.I.M.

Fulmer Research Institute, Ltd.

FIFTH EDITION



PRINTED IN  
ENGLAND BY  
RICHARD CLAY AND  
CO. LTD., BUNGAY, SUFFOLK

**BUTTERWORTHS**

London & Boston

<b>United Kingdom</b>	<b>Butterworth &amp; Co (Publishers) Ltd</b>
London	88 Kingsway, WC2B 6AB
<b>Australia</b>	<b>Butterworths Pty Ltd</b>
Sydney	586 Pacific Highway, Chatswood, NSW 2067
	Also at Melbourne, Brisbane, Adelaide and Perth
<b>Canada</b>	<b>Butterworth &amp; Co (Canada) Ltd</b>
Toronto	2265 Midland Avenue, Scarborough, Ontario, M1P 4S1
<b>New Zealand</b>	<b>Butterworths of New Zealand Ltd</b>
Wellington	77-85 Customhouse Quay, 1
<b>South Africa</b>	<b>Butterworth &amp; Co (South Africa) (Pty) Ltd</b>
Durban	152-154 Gale Street
<b>USA</b>	<b>Butterworth (Publishers) Inc</b>
Boston	19 Cummings Park, Woburn, Massachusetts 01801

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, including photocopying and recording, without the written permission of the copyright holder, application for which should be addressed to the Publishers. Such written permission must also be obtained before any part of this publication is stored in a retrieval system of any nature.

This book is sold subject to the Standard Conditions of Sale of Net Books and may not be re-sold in the UK below the net price given by the Publishers in their current price list.

First published 1949  
 Second edition 1955  
 Third edition 1962  
 Fourth edition 1967  
 Fifth edition 1976  
 Reprinted 1978

© Butterworth & Co (Publishers) Ltd 1976

ISBN 0 408 70627 9

1077067

Printed in England by R. J. Acford Ltd., Industrial Estate, Chichester

Bound by The Newdigate Press Ltd., Dorking, Surrey

# Contents

PREFACE TO THE FIFTH EDITION	v
FIRST AID	1
INTRODUCTORY TABLES	5
Weights and measures	5
Conversion factors	7
SI units	8
Conversions to and from SI units	10
Commonly required conversions	15
Conversion of temperatures IPTS48 to IPTS68	16
Corrosion conversion factors	17
Test sieve numbers converted to nominal apertures	17
Temperature conversion table °C/°F	18
Mathematical formulae	25
Algebra	25
Trigonometry	29
Mensuration	31
Co-ordinate geometry	32
Calculus	34
GENERAL PHYSICAL AND CHEMICAL CONSTANTS	53
Atomic weights and atomic numbers	53
General physical constants	54
Moments of inertia	55
Elementary particles	56
Periodic system	facing 57
Radioactive isotopes and radiation sources	57
X-RAY CRYSTALLOGRAPHY	64
Excitation of x-rays	64
X-ray technique	66
Intensity of x-ray reflections	75
Derivation of accurate unit cell dimensions in crystals	86
Radiation screening	92
X-ray results	95
Preferred orientation	96
Textures	97
Determination of crystal structure	98
CRYSTALLOGRAPHY	104
Structure of crystals	104
Schoenflies system of point and space group notation	108
Hermann-Mauguin system of point and space-group notation	108

<b>CRYSTAL CHEMISTRY</b>	115
Structures of metals, metalloids and their compounds	115
<b>METALLURGICALLY IMPORTANT MINERALS</b>	178
Ore grades and sources	179
<b>THERMOCHEMICAL DATA</b>	186
Symbols	186
Changes of phase	186
Elements	186
Intermetallic compounds	188
Other metallurgically important compounds	190
Heat, entropy and free energy of formation	193
Elements	193
Intermetallic compounds	193
Intermetallic phases	196
Metallic systems of unlimited mutual solubility	198
Liquid binary metallic systems	199
Metallurgically important compounds	203
Carbides	204
Nitrides	205
Oxides	206
Sulphides	208
Halides	210
Silicates and carbides	215
Phosphides	216
Sulphides	218
Molar heat capacity and specific heats	219
Elements	219
Alloy phases and intermetallic compounds	221
Borides	223
Carbides	224
Nitrides	224
Oxides	225
Sulphides, selenides and tellurides	227
Halides	228
Vapour pressures	231
Elements	231
Halides and oxides	233
<b>PHYSICAL PROPERTIES OF MOLTEN SALTS</b>	242
Density of pure molten salts	242
Density of molten binary salt systems	247
Density of some solid inorganic compounds at room temperature	258
Electrical conductivity of pure molten salts	259
Electrical conductivity of molten binary salt systems	267
Surface tension of pure molten salts	279
Surface tension of molten binary salt systems	281
Viscosity of pure molten salts	286
Viscosity of binary salt systems	288
<b>METALLOGRAPHY</b>	291
Macroscopic examination	291
Microscopic examination	291
Etching	292
Mounting	294
Grinding	295
Mechanical polishing	295
Electrolytic polishing	296
Chemical polishing	297
Etching reagents	308

Electron metallography	312
Transmission electron microscopy	312
Scanning electron microscopy	317
Qualitative image analysis	317
Metallographic methods	318
Aluminium	318
Antimony	323
Beryllium	323
Cadmium	324
Cobalt	325
Copper	326
Gold	330
Indium	330
Iron and steel	331
Lead	340
Magnesium	342
Molybdenum	346
Nickel	346
Niobium	348
Platinum group metals	348
Silicon	349
Silver	350
Tantalum	351
Tin	352
Titanium	353
Tungsten	354
Uranium	355
Zinc	356
Zirconium	357
Bearing metals, low melting solders and type metals	358
Cemented carbides and other hard alloys	359
Powdered and sintered metals	360
EQUILIBRIUM DIAGRAMS	364
Interconversion of atomic and weight percentages in binary systems	364
Binary equilibrium diagrams	370
Acknowledgments	802
Binary systems	802
Ternary systems	811
Quaternary systems	832
Quinary and higher systems	834
GAS-METAL SYSTEMS	835
The solution of gases in metals	835
Dilute solutions of diatomic gases	835
Complex gas-metal systems	836
Solutions of hydrogen	836
Solutions of nitrogen	847
Solutions of oxygen	851
Solutions of noble gases	855
Theoretical and practical aspects of gas-metal equilibria	855
DIFFUSION IN METALS	860
Introduction	860
Methods of measuring diffusion coefficients	863
Mechanisms of diffusion	865
Self-diffusion in solid elements	867
Tracer impurity diffusion coefficients	872
Diffusion in homogeneous alloys	886
Chemical diffusion coefficients	905
Chemical diffusion in ternary systems	927

Grain boundary self-diffusion	937
Self-diffusion coefficients in liquid metals	939
<b>GENERAL PHYSICAL PROPERTIES</b>	<b>940</b>
Pure metals at normal and elevated temperatures	940
Pure liquid metals	944
Density, surface tension, viscosity	944
Specific heat, thermal conductivity, electrical resistivity	947
Aluminium and aluminium alloys	951
Copper and copper alloys	953
Magnesium alloys	955
Nickel and nickel alloys	957
Titanium and titanium alloys	958
Zinc and zinc alloys	959
Zirconium alloys	959
Steels at normal, elevated and low temperatures	960
<b>ELASTIC PROPERTIES AND DAMPING CAPACITY</b>	<b>975</b>
Elastic constants	975
Single crystals	976
Damping capacity	980
Commercial alloys	980
Anelastic damping	981
Ferro-elastic metals	1002
<b>TEMPERATURE MEASUREMENT AND THERMOELECTRIC PROPERTIES</b>	<b>1007</b>
Fixed points for calibration	1007
Thermotive force of the elements and binary alloys	1008
Absolute thermoelectric power of platinum	1009
Thermocouple reference tables	1010
Precious metal thermocouples	1010
Base metal thermocouples	1011
<b>RADIATING PROPERTIES OF METALS</b>	<b>1014</b>
Total and spectral emissivity	1014
Temperature measurement and emissivity	1017
Spectral emissivity of metals	1019
Oxidised surfaces	1022
Total emissivity of metals	1023
<b>ELECTRON EMISSION</b>	<b>1026</b>
Thermionic	1026
Photoelectric	1029
Secondary	1030
Auger	1032
Positive ion bombardment	1033
Field emission	1033
<b>ELECTRICAL PROPERTIES</b>	<b>1035</b>
Resistivity of pure metals and alloys	1035
Superconductivity	1041
<b>STEELS AND ALLOYS WITH SPECIAL MAGNETIC PROPERTIES</b>	<b>1044</b>
Magnetic definitions	1044
Magnetic units and conversion factors	1046
Materials with magnetic properties	1046
Mass susceptibilities	1047
Permanent magnet alloys	1048
Steels and cast irons	1049

Magnetically soft materials	1053
Low hysteresis loss materials	1053
High permeability materials	1059
Constant permeability materials	1059
Magnetic powder core materials	1062
Magnetic temperature compensating materials	1062
Non-magnetic steels and cast irons	1063
MECHANICAL TESTING	1065
Hardness tests	1065
Hardness conversion tables	1067
Tensile testing	1072
Impact testing	1074
Plane strain fracture toughness testing	1076
MECHANICAL PROPERTIES OF METALS AND ALLOYS	1081
Aluminium and aluminium alloys	1082
Specifications	1082
Mechanical properties at room temperature	1083
Mechanical properties at elevated temperatures	1093
Mechanical properties at low temperatures	1098
Creep data	1100
Fatigue strength at various temperatures	1102
Copper and copper alloys	1103
Specifications	1103
Mechanical properties at room temperature	1104
Mechanical properties at elevated temperatures	1108
Fatigue properties at room temperature	1114
Impact properties	1115
Creep properties	1117
Lead and lead alloys	1126
Mechanical properties at room temperature	1126
Magnesium and magnesium alloys	1129
Mechanical properties at room temperature	1129
Mechanical properties at elevated temperatures	1132
Creep properties	1134
Fatigue and impact strengths	1136
Nickel and nickel alloys	1139
Specifications	1139
Mechanical properties at room temperature	1142
Mechanical properties at elevated temperatures	1144
Mechanical properties at cryogenic temperatures	1145
Fatigue properties	1146
Creep properties	1147
Titanium and titanium alloys	1148
Specifications	1148
Mechanical properties at room temperature	1150
Mechanical properties at elevated temperatures	1152
Creep properties	1156
Fatigue properties	1157
Impact properties	1159
Zinc and zinc alloys	1160
Mechanical properties at room temperature	1160
Zirconium and zirconium alloys	1160
Mechanical properties at room temperature	1160
Mechanical properties at elevated temperatures	1161
Steels	1162
Mechanical properties at room temperature	1162
Mechanical properties at elevated temperatures	1197

Fatigue properties	1202
Creep properties	1206
Mechanical properties at low temperature	1209
Tool steels	1214
Cast irons and cast steels	1221
Mechanical properties at room temperature	1221
Mechanical properties at elevated temperatures	1244
Creep properties	1247
Mechanical properties at low temperatures	1250
Steel weld metal	1252
Mechanical properties at room temperature	1252
Other metals of industrial importance	1257
Bearing metals	1259
<b>HARD METALS</b>	<b>1262</b>
Properties of compounds	1262
Mutual solubilities of compounds	1263
Properties of typical hard metals	1264
<b>LUBRICANTS</b>	<b>1265</b>
Friction, wear and boundary lubrication	1265
Characteristics of lubricating oils	1266
Mineral oils	1267
Emulsions	1270
Water-based lubricants	1270
Synthetic oils	1270
Greases	1272
Oil additives	1274
<b>FRICITION AND WEAR</b>	<b>1277</b>
Friction	1277
Unlubricated surfaces	1277
Boundary lubrication	1282
Wear	1287
<b>CASTING ALLOYS AND FOUNDRY DATA</b>	<b>1290</b>
Glossary	1290
Casting techniques	1291
Patterns	1300
Pattern materials	1302
Crucibles and melting vessels	1305
Aluminium alloys	1314
Copper-base alloys	1324
Nickel-base alloys	1336
Magnesium alloys	1340
Zinc alloys—pressure die casting	1347
Steel castings	1349
Carbon steels	1350
Alloy steels	1352
Austenitic and heat resisting steels	1356
Typical applications	1362
Investment castings, steels, nickel and cobalt alloys	1367
Grey iron castings	1383
Malleable iron castings	1389
Nodular iron castings	1391
Special purpose cast irons	1392
<b>REFRACTORY MATERIALS</b>	<b>1396</b>
Glossary	1396
Raw materials	1398



Heat insulating materials	1399
Refractory materials	1399
<b>FUELS</b>	1410
Coal	1410
Analysis and testing	1410
Classification and properties	1413
Metallurgical coke	1416
Gaseous fuels, liquid fuels and energy requirements	1420
Liquid fuels	1420
Gaseous fuels	1423
Fuel material and energy data	1429
<b>CONTROLLED ATMOSPHERES FOR HEAT TREATMENT</b>	1438
Chemistry of controlled atmosphere processes	1438
Types of controlled atmospheres	1440
Purification	1444
Applications to ferrous alloys	1445
Applications to non-ferrous alloys	1452
<b>MASERS AND LASERS</b>	1454
Optical maser materials	1454
<b>GUIDE TO THE CORROSION RESISTANCE OF METALS</b>	1460
Forms of corrosion in metals	1462
Corrosion resistance guide	1466
Localised corrosion effects	1481
Coatings	1483
<b>ELECTROPLATING AND METAL FINISHING</b>	1486
Polishing compositions	1486
Cleaning and pickling processes	1487
Anodising and plating processes	1490
Plating processes for magnesium alloys	1500
Methods of stripping electroplated coatings	1503
Protection of magnesium-base alloys by chromating	1505
Glossary of trade names for coating processes	1506
<b>WELDING</b>	1510
Glossary of welding terms	1510
Resistance welding	1513
Friction welding	1518
Fusion welding	1519
Ferrous metals	1520
Non-ferrous metals	1533
British Standards relating to welding	1544
<b>SOLDERS AND BRAZING ALLOYS</b>	1548
Specifications	1548
Solders	1548
Brazing alloys	1550
<b>INDEX</b>	1553

*Editor*

Colin J. Smithells, M.C., D.Sc., F.I.M.

*Assistant editor*

Eric A. Brandes, B.Sc., A.R.C.S., F.I.M.

*Contributors to this edition*

V. Ashworth, Ph.D., A.R.I.C., M.I.Corr.T.  
T. D. Boxall  
G. B. Brook, B.Met.(Shef.), F.I.M.  
M. R. Brozel, B.Sc., M.Sc., Ph.D.  
G. R. Campbell  
J. Campbell, M.A., M.Met., A.I.M., Ph.D.  
B. Cartwright, A.Met., A.I.M., A.Weld.I.  
A. R. L. Chivers, M.A.  
D. N. Collins, B.Sc., A.R.S.M., M.I.M.M., C.Eng.  
M. Deighton, B.Sc., Ph.D., A.I.M.  
M. A. E. Dewey, F.I.M.  
D. M. Dovey, M. A., F.R.I.C., F.I.M.  
P. Elliott, M.Sc., Ph.D.  
M. F. Finlan, B.Sc., M.Inst.P.  
P. A. Fisher, B.Sc., F.I.M.  
I. N. Fitzpatrick, M.Sc., Ph.D., A.I.M.  
M. L. H. Flindt, M.B., B.S., L.R.C.P., M.R.C.S., D.I.H.  
P. J. Foster, B.Sc.Tech., Ph.D., C.Eng., M.I.Ch.E., A.M.Inst.F.  
T. I. Fowle, B.Sc.(Eng.), F.I.Mech.E.  
B. Gill, M.Sc.Tech., Ph.D.  
T. G. Gooch, B.Sc., M.Sc.(Eng.), D.I.C., A.I.M., M.Weld.I.  
B. A. Hatt, B.Sc., M.Sc.(Eng.), M.Inst.P.  
D. Herrell, B.Sc.  
W. C. Heselwood, B.Sc., A.Met., Mist.M.C., F.I.M., F.Inst.P.  
J. Hinde, F.I.M., F.Weld.I., A.R.Ae.S.  
W. J. Jackson, Ph.D., M.Sc.(Eng.), F.R.I.C., F.I.M.  
R. O. Jenkins, A.R.C.S., D.I.C., Ph.D., F.Inst.P.  
A. J. King, D.C.T., A.I.M.  
P. Kovesi, D.Met., A.I.M., M.I.Inf.Sc.  
A. D. LeClaire, B.A.(Cantab.), F.Inst.P.  
D. N. Moir, B.Sc., A.R.S.M., M.I.M.M., C.Eng.  
L. D. Muller, B.Sc., M.I.M.M., C.Eng.  
J. K. R. Page, B.A.  
K. L. Preddy, M.Sc., A.M.I.B.F.  
R. L. Preece, B.Sc.  
T. J. Quinn, B.Sc., D.Phil., M.Inst.P.  
E. E. Riches, M.Sc., C.Eng., M.I.E.E., M.Inst.P.  
V. G. Rivlin, B.A., D.Phil.  
J. P. Scholes, B.Sc., M.Sc., C.Eng., M.I.Mech.E.  
D. Tabor, Ph.D.(Cantab.), Sc.D.(Cantab.), F.R.S.  
D. E. J. Talbot, M.Sc., A.I.M.  
S. G. Temple, M.B.E., M.Sc., A.C.T., F.I.M.  
C. J. Thwaites, M.Sc.(Eng.), A.R.S.M., M.I.Brit.F., F.I.M.F., F.I.M.  
M. B. Waldron, Ph.D., F.I.M.  
T. G. Walker, B.Sc., Ph.D.  
A. J. Wall, B.Sc., Ph.D.  
R. Warren, B.Sc., Ph.D.  
H. C. Wesson, B.Sc., M.A., F.R.I.C.  
M. J. Wheeler, B.Tech., M.Inst.P.  
G. W. Wilson, B.Sc., Ph.D., F.Inst.P., A.I.M., M.I.E.E., M.I.E.R.E.  
M. J. Woolley, M.Sc., Ph.D.