**INTERACTION OF
METALS AND GASES**

PHILIPS TECHNICAL LIBRARY

INTERACTION OF METALS AND GASES

Vol. 2

Kinetics and Mechanisms

J. D. FAST

*Chief Metallurgist Philips Research Laboratories
and Professor at the Technical University of Eindhoven*

MACMILLAN

English edition © N. V. Philips' Gloeilampenfabrieken, Eindhoven, 1971

Softcover reprint of the hardcover 1st edition 1971 978-0-333-07564-7

*All rights reserved. No part of this publication may be reproduced
or transmitted in any form or by any means, without permission.*

SBN 333 07564 1

ISBN 978-1-349-00502-4

ISBN 978-1-349-00500-0 (eBook)

DOI 10.1007/978-1-349-00500-0

First published by

MACMILLAN PRESS LTD.

London and Basingstoke

*Associated companies in New York, Toronto, Melbourne,
Dublin, Johannesburg and Madras*

PHILIPS

Trademarks of N. V. Philips' Gloeilampenfabrieken

PREFACE

Like the first volume of 'Interaction of Metals and Gases' this second volume with the sub-title 'Kinetics and Mechanisms' handles the theoretical background as simply as possible. It has been written for metallurgical students, industrial metallurgists and chemists. Three subjects have been omitted from the book, those of adsorption, catalysis and oxidation, not because they are unimportant but rather because they are so all-important that a large number of excellent books are already devoted to them. Consequently this volume, with the exception of Section 4.12, deals exclusively with the behaviour of gases in the interior of metals, leaving interactions with metal surfaces out of consideration.

Eindhoven, October 1971

J. D. Fast

CONTENTS

Chapter 1. SOLUTIONS OF GASES IN METALS

1.1. Foreign interstitial solute atoms in metals	1
1.2. Size of the interstices	3
1.3. Effect of the size factor	7
1.4. Redistribution of interstitial atoms following lattice distortion	15
1.5. Electronic interaction	21
1.6. Chemical factors	24
1.7. Brillouin zones and energy bands	27
1.8. Fermi surface and electronic specific heat	36
1.9. Hydrogen in palladium	39
1.10. Hydrogen in palladium alloys	48
1.11. Hydrogen in nickel	64
1.12. The nature of bonding in transition-metal hydrides	73
1.13. Confrontation of proton theory and anion theory	79
1.14. Oxygen in transition metals and in transition-metal alloys	84

Chapter 2. DIFFUSION IN INTERSTITIAL ALLOYS

2.1. Introduction	88
2.2. Steady-state diffusion	88
2.3. Non-steady-state diffusion	92
2.4. Measurement of diffusivities of gases in metals	97
2.5. Dependence of diffusivity on concentration	100
2.6. Concentration and chemical potential	108
2.7. The statistical nature of diffusion	112
2.8. Atomic and macroscopic treatment of diffusion problems	116
2.9. Interstitial diffusion in fcc and bcc metals	120
2.10. The influence of temperature	123

2.11. The value of D_0 for the diffusion of hydrogen	130
2.12. The entropy of activation for interstitial diffusion	132
2.13. Diffusion of hydrogen in iron	133
2.14. Diffusion of carbon in iron	142
2.15. Diffusion along grain boundaries and dislocations	148
 Chapter 3. INTERNAL FRICTION OF METALS	
3.1. Introduction	159
3.2. Relaxation and hysteresis	159
3.3. Relaxation caused by phonons and electrons	164
3.4. Relaxation associated with grain boundaries	166
3.5. The Snoek effect	169
3.6. Relaxation due to interstitial atoms in fcc alloys	171
3.7. Relaxation due to reorientation of pairs of point defects	174
3.8. More about relaxation due to pairs of point defects	175
3.9. The Zener relaxation	179
3.10. Relaxation associated with dislocations	181
3.11. Hysteresis due to dislocations	184
3.12. Hysteresis due to domain walls	189
 Chapter 4. THE SNOEK EFFECT AND ITS SIGNIFICANCE FOR METAL-GAS PROBLEMS	
4.1. Relaxation time	195
4.2. Compliance	196
4.3. Time-dependent fields or stresses: derivation of the Debye equations	198
4.4. Derivation of the Debye equations without recourse to complex variables	201
4.5. The significance of the Debye equations for the Snoek effect	205
4.6. Checking the elementary theory with experimental data	208
4.7. Thermodynamic considerations	212
4.8. Relations between measures of internal friction	218
4.9. Determination of diffusivities of interstitial atoms	220
4.10. Determination of solubilities	225
4.11. Discovery of new phases	232

CONTENTS

ix

4.12. Study of surface reactions	236
4.13. Analytical determination of small quantities of carbon and nitrogen in iron	242
4.14. Interaction of interstitial atoms	244
4.15. Study of the kinetics of precipitation	253
4.16. Interaction between interstitial and substitutional atoms	255
4.17. Interaction between interstitial and substitutional atoms in the presence of a precipitate	265
4.18. Influence of quantum effects on diffusion	269
 Chapter 5. INTERACTION OF INTERSTITIALS AND OTHER LATTICE IMPERFECTIONS	
5.1. Interaction of foreign interstitials and dislocations	271
5.2. Yield point and strain-ageing	276
5.3. Segregation and precipitation	280
5.4. Exchange of solutes at dislocations	281
5.5. The cold-work peak	285
5.6. Interaction of interstitials and grain boundaries	292
5.7. Interaction of interstitials and domain boundaries	295