Series on Advances in Mathematics for Applied Sciences – Vol. 44

Microscopic Theory of Condensation in Gases and Plasma

A. L. Itkin

E. G. Kolesnichenko

International Institute for Problems of the Asteroid Hazard
Moscow, Russia

World Scientific
Singapore • New Jersey • London • Hong Kong

Published by

World Scientific Publishing Co. Pte. Ltd.

P O Box 128, Farrer Road, Singapore 912805

USA office: Suite 1B, 1060 Main Street, River Edge, NJ 07661

UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

Library of Congress Cataloging-in-Publication Data

Itkin, A. L.

Microscopic theory of condensation in gases and plasma / A. L. Itkin & E. G. Kolesnichenko.

p. cm. -- (Series on advances in mathematics for applied sciences; vol. 44)

Includes bibliographical references.

ISBN 9810229070 (alk. paper)

1. Gases -- Absorption and adsorption. 2. Nucleation. 3. Condensation. 4. Kinetic theory of gases. I. Kolesnichenko, E. G. II. Title. III. Series.

QC162.I85 1997

536'.44--dc21 97-3965

CIP

British Library Cataloguing-in-Publication Data

A catalogue record for this book is available from the British Library.

Copyright © 1997 by World Scientific Publishing Co. Pte. Ltd.

All rights reserved. This book, or parts thereof, may not be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage and retrieval system now known or to be invented, without written permission from the Publisher.

For photocopying of material in this volume, please pay a copying fee through the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. In this case permission to photocopy is not required from the publisher.

This book is printed on acid-free paper.

Printed in Singapore by Uto-Print

Contents

1 Brief review of the existing nucleation theories **1**
1. Quasichemical model of condensation 2
1.1. Basic statements of the model 2
1.2. Discussion 4
1.3. Methods of solving 5
2. Classical nucleation theory 8
2.1. Critical size 8
2.2. Reaction rate constants 9
2.3. Basic equations of the theory 10
2.4. Some problems of CNT 12
3. Lothe and Pound nucleation theory 15
4. Failures in the prediction of the experimental data 17

2 Main principles of the microscopic theory of condensation **21**
1. Formulation of the problem 22
2. Equilibrium solutions 25
2.1. General approach to deriving the equilibrium distribution . 25
2.2. Example of the partition function for a simple model of the cluster 30
2.3. Analysis of peculiarities of the phase transition 34
3. Quasisteady solutions 38
3.1. Derivation of equations for concentrations 40
3.2. Method of solving the equations for concentrations 47
3.3. Equations in f variables 49
4. Constants and parameters of the theory 55
4.1. Cluster dissociation rate 56
4.2. The topmost level M_j 59
4.3. Activation energy 61

4.4. Condensation coefficient 62
4.5. Parameter r 63
4.6. Parameter j_* 67
5. Short summary of main formulae 69
5.1. The main equations 69
5.2. Parameters and constants of the theory 70

3 Juxtaposition with the other theories and experiments 75
1. Comparison with the existing theories 75
1.1. Nucleation 76
1.2. Droplets growth 79
2. Comparison with experimental data 82
2.1. Flows of the condensible vapor in nozzles and jets 85
2.2. Transport processes in a thermal diffusion chamber under nucleation 99
2.3. Scaling relations and crucial parameters 109
2.4. Results of the comparison with experiments for pure vapors 117
2.5. Influence of a carrier gas on the condensation kinetics . . . 138

4 Kinetic theory of photostimulated nucleation 147
1. Statement of the problem. Governing equations 148
2. Stationary solutions 152
3. Quasisteady-state method 154
3.1. The first step 154
3.2. The second step 157
4. Discussion 159
5. Analysis of model assumptions 164
6. Analysis of the experimental data 168

5 Kinetic theory of ion–induced nucleation 175
1. Short review of the existing approaches 176
2. Formulation of the problem 177
3. Equilibrium solutions 180
3.1. Equations for determining the equilibrium concentrations . 181
3.2. Equilibrium constants K_j^ν, $\nu = 0, i, e$ 183
4. Solution of the kinetic equations. Quasisteady states 187
4.1. The first stage of the quasisteady-state method 187
4.2. The second stage of the quasisteady-state method 195
5. An analysis of specific features of heterogeneous condensation on ions and electrons 201

5.1. An analysis of equations for supersaturations 201
5.2. Heterogeneous condensation in expanding flows 211

Conclusions **219**

Appendices **225**
A. Dimensionless form of the system Eq. (2.2) 225
B. Low-pressure limit ($j = 2, \ldots, r-1$) 228
B.1. Region 3 ($k \leq p_j$) 230
B.2. Region 2 ($k = p_j + 1, \ldots, q_j$) 230
B.3. Region 1 ($k = q_j + 1, \ldots, M_j$) 231
B.4. Intermediate case $j = r$ 233
C. Quasisteady equations for concentrations 234
C.1. High-pressure limit ($j > r$) 234
C.2. Intermediate case ($j = r$) 234
C.3. Low-pressure limit ($j < r$) 236
C.4. Equations for monomers ($j = 1$) 238
D. FORTRAN subroutines for computing parameters of the theory . 240
D.1. Initial data 240
D.2. Parameter r 244
D.3. Function j_* 249
D.4. Function K_j^- 251
D.5. Function n_{je} 252
D.6. Quasisteady concentrations n_j 256

References **263**

Index **271**