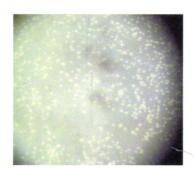
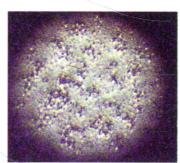
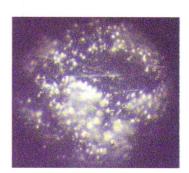
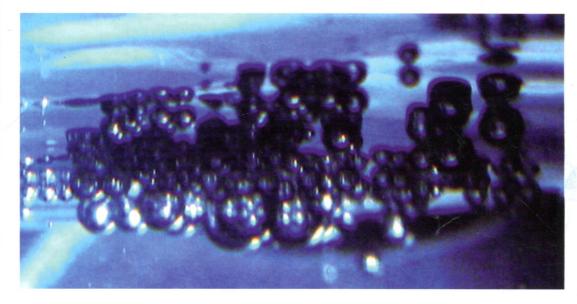
V. G. Baidakov

Explosive Boiling of Superheated Cryogenic Liquids









Vladimir G. Baidakov

Explosive Boiling of Superheated Cryogenic Liquids



WILEY-VCH Verlag GmbH & Co. KGaA

The Author

Vladimir G. Baidakov Institute of Thermal Physics

Russian Academy of Sciences Ekaterinburg, Russian Federation

bai@itp.uran.ru

Consultant Editor

Jürn W. P. Schmelzer Physics Department

University of Rostock

Rostock, Germany

juern-w.schmelzer@uni-rostock.de

Cover illustration

Explosive boiling-up of gas-saturated liquid solutions

by V. S. Uskov, Institute of Thermal Physics of the Ural Branch

of the Russian Academy of Sciences

All books published by Wiley-VCH are carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained in these books, including this book, to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may

Library of Congress Card No.:

inadvertently be inaccurate.

applied for

British Library Cataloguing-in-Publication Data

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

Bibliographic information published by

the Deutsche Nationalbibliothek

Internet at http://dnb.d-nb.de>.

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie;

detailed bibliographic data are available in the

© 2007 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

All rights reserved (including those of translation

into other languages). No part of this book may be reproduced in any form - by photoprinting, microfilm, or any other means - nor transmitted or translated into a machine language without written permission from the publishers.

Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

Typesetting Uwe Krieg, Berlin Printing Strauss GmbH, Mörlenbach Binding Litges & Dopf GmbH, Heppenheim

Wiley Bicentennial Logo Richard J. Pacifico

Printed in the Federal Republic of Germany Printed on acid-free paper

ISBN 978-3-527-40575-6

Contents

	Foreword V
	Preface XI
1	Introduction 1
2	Equilibrium, Stability, and Metastability 7
2.1	Types of Equilibria: Stability Criteria 7
2.2	Boundary of Essential Instability 13
2.3	Elements of Statistical Theory 16
2.4	Phase Stability Against Finite Perturbations 19
2.5	Critical Heterophase Fluctuations 23
2.6	Relaxation Processes in Metastable Phases 26
2.7	Dynamics of Heterophase Fluctuations 30
2.8	Kinetic Nucleation Theory (Multiparameter Version) 35
2.9	Approximations and Limitations of Classical Nucleation Theory 41
2.10	Nucleation at a High Degree of Metastability 47
2.11	Nucleation Bypassing the Saddle Point 51
2.12	Some Comments on Nucleation Theory 57
3	Attainable Superheating of One-Component Liquids 61
3.1	Two Approaches to the Determination of the Work of Formation of a
	Critical Bubble 61
3.2	Boiling-Up Kinetics of Superheated Liquids 65
3.3	Elements of the Stochastic Theory of Nucleation 74
3.4	Experimental Procedures in the Analysis of Boiling in Superheated
	Liquids 78
3.5	Quasistatic Methods of Investigating Limiting Superheatings of
	Liquids 82
3.6	Dynamic Methods of Investigating Explosive Boiling-Up of
	Liquids 88

Explosive Boiling of Superheated Cryogenic Liquids. Vladimir G. Baidakov Copyright © 2007 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim ISBN: 978-3-527-40575-6

VIII	Contents	
	3.7	Results of Experiments on Classical Liquids 91
	3.8	Superheating of Quantum Liquids 107
	3.9	Surface Tension of Vapor Nuclei 116
	3.10	Cavitation Strength of Cryogenic Liquids 123
	3.11	Attainable Superheating of Liquid Argon at Negative
		Pressures 138
	3.12	Initiated Nucleation 145
	3.13	Heterogeneous Nucleation 151
	4	Nucleation in Solutions of Liquefied Gases 159
	4.1	Critical Nucleus and the Work of its Formation 159
	4.2	Theory of Nucleation in Binary Solutions 165
	4.3	Attainable Superheating of Solutions of Hydrocarbons 172
	4.4	Methods of Experimentation on Solutions of Cryogenic
		Liquids 174
	4.5	Solutions with Complete Solubility of the Components 177
	4.6	Solutions with Partial Solubility of the Components 182
	4.7	Equation of State and Boundaries of Thermodynamic Stability of
		Solutions 190
	4.8	Properties of Critical Bubbles in Binary Solutions 195
	4.9	Comparison of Theory and Experiment for Binary Solutions 204
	4.10	Kinetics and Thermodynamics of Nucleation in Three-Component
		Solutions 209
	4.11	Attainable Superheatings of Ternary Solutions of Cryogenic
		Liquids 213
	5	Nucleation in Highly Correlated Systems 219
	5.1	Introduction 219
	5.2	Critical Configuration and its Stability 222
	5.3	Steady-State Nucleation 228
	5.4	Peculiarities of New Phase Formation in the Critical Region 232
	5.5	Experimental Investigations of Nucleation in the Vicinity of Critical
		and Tricritical Points 240
	5.6	Comparison of Theory and Experiment 245
	5.7	Nucleation in the Vicinity of a Spinodal Curve 253
	5.8	Theory of Spinodal Decomposition 259
	5.9	Experimental Studies of Spinodal Decomposition 266
	6	Nucleation Kinetics Near the Absolute Zero of Temperature 273
	6.1	Quantum Tunneling of Nuclei 273
	6.2	Limiting Supersaturations of ⁴ He– ³ He-Solutions 278
	6.3	Formation of Quantum Vortices in Superfluid Helium 284

6.4	Quantum Nucleation Near the Boundary of Essential Instability 289	
6.5	Quantum Cavitation in Helium 294	
6.6	Some Other Problems of Phase Metastability 299	
7	Explosive Boiling-Up of Cryogenic Liquids 309	
7.1	Superheating in Outflow Processes 309	
7.2	Vapor Explosion at the Interface of Two Different Liquids	314
	List of Symbols 321	
	References 323	

Index 337