## **CONTENTS**

Electron Spin Resonance Studies of Supercooled Water	1
By Debamalya Banerjee, Subray V. Bhat, and Dino Leporini	
Pressure-Driven Liquid–Liquid Transformations and Corresponding Bizarre Viscosity Behavior	29
By Vadim V. Brazhkin, Yoshinori Katayama, Masami Kanzaki, and Alexander G. Lyapin	
The Stability Limit and Other Open Questions on Water at Negative Pressure	51
By Frédéric Caupin and Abraham D. Stroock	
Water-Like Anomalies of Core-Softened Fluids: Dependence on the Trajectories in $(P ho T)$ Space	81
By Yu. D. Fomin and V. N. Ryzhov	
High-Frequency Dynamics of Liquids Through a Liquid–Liquid Transition: The Case of CS	101
By Valentina Maria Giordano and G. Monaco	
The Liquid–Liquid Phase Transition, Anomalous Properties, and Glass Behavior of Polymorphic Liquids	113
By Nicolas Giovambattista	
Amorphous ICES	139
By Nicolas Giovambattista, Katrin Amann-Winkel, and Thomas Loerting	
Water Proton Environment: A New Water Anomaly at Atomic Scale?	175
By A. Giuliani, M. A. Ricci, and F. Bruni	
Polymorphism and Anomalous Melting in Isotropic Fluids	189
By Gianpietro Malescio	

xviii CONTENTS

TRANSPORT AND DYNAMICS IN SUPERCOOLED CONFINED WATER	203
By Francesco Mallamace, Carmelo Corsaro, Sow-Hsin Chen, and H. Eugene Stanley	
Water and Biological Macromolecules	263
By Francesco Mallamace, Carmelo Corsaro, Domenico Mallamace, H. Eugene Stanley, and Sow-Hsin Chen	
Polyamorphism and Liquid–Liquid Phase Transitions in Amorphous Silicon and Supercooled $A {\rm L}_2 O_3 - Y_2 O_3$ Liquids	309
By Paul F. McMillan, G. Neville Greaves, Mark Wilson, Martin C. Wilding, and Dominik Daisenberger	
Polyamorphism in Water	355
By Osamu Mishima	
Computer Simulations of Liquid Silica: Water-Like Thermodynamic and Dynamic Anomalies, and the Evidence for Polyamorphism	373
By Ivan Saika-Voivod and Peter H. Poole	
Polymorphism in Lattice Models	385
By Marcia M. Szortyka, Mauricio Girardi, Carlos E. Fiore, Vera B. Henriques, and Marcia C. Barbosa	
Cooperative Bond Ordering in Liquid: Its Link to Liquid Polymorphism and Water-Like Anomalies	399
By Hajime Tanaka	
Statistical Mechanical Approach to the Thermodynamic Stability of Clathrate Hydrates	421
By Hideki Tanaka and Masakazu Matsumoto	
Liquid–Liquid Phase Transition in Supercooled Silicon	463
By Vishwas V. Vasisht and Srikanth Sastry	
Similarities of the Collective Interfacial Dynamics of Grain Boundaries and Nanoparticles to Glass-Forming Liquids	519
By Hao Zhang and Jack F. Douglas	
Author Index	569
Subject Index	611
	0.1

## ELECTRON SPIN RESONANCE STUDIES OF SUPERCOOLED WATER

DEBAMALYA BANERJEE, 1 SUBRAY V. BHAT, 1 and DINO LEPORINI<sup>2,3</sup>

<sup>1</sup>Department of Physics, Indian Institute of Science, Bangalore 560 012, India

<sup>2</sup>Dipartimento di Fisica "Enrico Fermi," Università di Pisa, Largo B.

Pontecorvo 3, I-56127 Pisa, Italy

<sup>3</sup>IPCF-CNR, UoS Pisa, Italy

## **CONTENTS**

- I. Introduction
- II. Outline of ESR Spectroscopy
  - A. Spin Probes
  - B. Rigid-Limit and Motional Narrowing of the Lineshape
  - C. Accessible Range of the Rotational Dynamics
- III. ESR Spectroscopy of Spin Probes: Basic Theoretical Introduction
  - A. Spin Hamiltonian
  - B. Lineshape Analysis
    - 1. No Tumbling: Powder Lineshape
    - 2. Tumbling: Motional Narrowing of the ESR Lineshape
- IV. ESR Studies of Liquid Water and Aqueous Solutions: A Review
- V. ESR Studies of Confined Water in Polycrystalline Ice
  - A. Water Confinement in Polycrystalline Ice
  - B. Location of Paramagnetic Solutes in Water-Ice Mixtures
  - C. Rotational Dynamics of TEMPOL in Interstitial Water of Polycrystalline Ice
    - 1. Spin Probe Mobility Above 130K
    - 2. Dynamical Heterogeneities
    - 3. Temperature Dependence of the Spin Probe Reorientation
    - 4. Breakdown of the Debye-Stokes-Einstein Law
    - 5. Spin Probe Sensing of the Water Static Heterogeneities
    - 6. Missing Evidence of Additional Impurities in Interstitial Water

VI. Summary

References

Liquid Polymorphism: Advances in Chemical Physics, Volume 152, First Edition.

Edited by H. Eugene Stanley.

© 2013 John Wiley & Sons, Inc. Published 2013 by John Wiley & Sons, Inc.

# PRESSURE-DRIVEN LIQUID-LIQUID TRANSFORMATIONS AND CORRESPONDING BIZARRE VISCOSITY BEHAVIOR

VADIM V. BRAZHKIN,<sup>1</sup> YOSHINORI KATAYAMA,<sup>2</sup> MASAMI KANZAKI,<sup>3</sup> and ALEXANDER G. LYAPIN,<sup>1</sup>

<sup>1</sup>Institute for High Pressure Physics RAS, 142190 Troitsk Moscow Region, Russia <sup>2</sup>Japan Atomic Energy Agency (JAEA), SPring-8, 1-1-1 Kuoto, Sayo-cho, Sayo-gun, Hyogo 679-5143, Japan <sup>3</sup>Institute for Study of the Earth Interior, Okayama University, Yamada 827, Misasa, Tottori 682-0193, Japan

## **CONTENTS**

- I. Introduction
- II. Methods
- III. Results and Discussions
  - A. Se
  - B. AsS
  - C. As<sub>2</sub>S<sub>3</sub>
  - D. B<sub>2</sub>O<sub>3</sub>
- IV. Conclusions

# THE STABILITY LIMIT AND OTHER OPEN QUESTIONS ON WATER AT NEGATIVE PRESSURE

## FRÉDÉRIC CAUPIN<sup>1</sup> and ABRAHAM D. STROOCK<sup>2</sup>

<sup>1</sup>Institut Lumière Matière, UMR5306 Université Lyon 1-CNRS, Institut Universitaire de France, Université de Lyon 69622 Villeurbanne cedex, France <sup>2</sup>School of Chemical and Biomolecular Engineering, Cornell University, Ithaca, NY 14853, USA

## **CONTENTS**

- I. Introduction
- II. What is Negative Pressure?
- III. The Phase Diagram of Water
- IV. Experimental Methods to Generate Tension
  - A. Acoustic Cavitation
  - B. Metastable Vapor-Liquid Equilibrium
  - C. Berthelot Tube
  - D. Centrifuge Method
- V. Limit(s) of Metastability
  - A. Comparison Between the Different Methods
  - B. Origin of the Discrepancy in the Limits of Metastability
  - C. Remaining Issues with Inclusions
  - D. Path-Dependent Nucleation
- VI. Other Topics in the Study of Liquids Under Tension
  - A. Equation of State of Water at Negative Pressure
  - B. Other Properties of Liquid at Negative Pressure

VII. Perspectives

# WATER-LIKE ANOMALIES OF CORE-SOFTENED FLUIDS: DEPENDENCE ON THE TRAJECTORIES IN $(P\rho T)$ SPACE

YU. D. FOMIN and V. N. RYZHOV

Institute for High Pressure Physics, Russian Academy of Sciences, Troitsk 142190, Moscow Region, Russia

### CONTENTS

- I. Introduction
- II. System and Methods
- III. Results and Discussion
  - A. Diffusion Anomaly
  - B. Density Anomaly
  - C. Structural Anomaly
- IV. Rosenfeld Scaling

V. Conclusions

## HIGH-FREQUENCY DYNAMICS OF LIQUIDS THROUGH A LIQUID-LIQUID TRANSITION: THE CASE OF CS

VALENTINA MARIA GIORDANO<sup>1,2</sup> and GIULIO MONACO<sup>2</sup>

<sup>1</sup>Institut Lumière Matière, UMR5306 Université Lyon 1-CNRS, Université de Lyon 69622 Villeurbanne cedex, France

<sup>2</sup>European Synchrotron Radiation Facility, 6 rue Jules Horowitz, BP220, 38043

Grenoble Cedex, France

#### **CONTENTS**

- I. Introduction
- II. The Case of Liquid Cesium
- III. The Experiment
- IV. Results
- V. Discussion
- VI. Conclusions

## THE LIQUID-LIQUID PHASE TRANSITION, ANOMALOUS PROPERTIES, AND GLASS BEHAVIOR OF POLYMORPHIC LIQUIDS

## NICOLAS GIOVAMBATTISTA

Department of Physics, Brooklyn College of the City University of New York, Brooklyn, NY 11210-2889, USA

## **CONTENTS**

- I. Introduction
- II. Polymorphic Liquids: Phase Diagram, Anomalous Properties, and Glass Behavior
  - A. Liquid-Liquid Phase Transition
  - B. Supercritical Region: Anomalous Properties
  - C. Glass Polymorphism
- III. Computer Simulation Models of Polymorphic Liquids
- IV. Summary and Discussion

## **AMORPHOUS ICES**

## NICOLAS GIOVAMBATTISTA<sup>1</sup>, KATRIN AMANN-WINKEL<sup>2</sup>, and THOMAS LOERTING<sup>2</sup>

<sup>1</sup>Physics Department, Brooklyn College of the City University of New York, Brooklyn, NY 11210-2889, USA <sup>2</sup>Institute of Physical Chemistry, University of Innsbruck, Innrain 52a, A-6020 Innsbruck, Austria

#### CONTENTS

- I. Introduction
- II. Pressure-Induced Amorphization of Hexagonal Ice: High-Density Amorphous Ice (HDA)
- III. Low-Density Amorphous Ice (LDA)
- IV. Apparent First-Order Transition Between Low- and High-Density Amorphous Ice
- V. An Interpretation of Amorphous Ice Phenomenology from Computer Simulations
- VI. Different States of Relaxation in HDA
- VII. Very High-Density Amorphous Ice (VHDA)
- VIII. Molecular Structure of Amorphous Ices
  - IX. VHDA in Computer Simulations
  - X. The Glass-to-Liquid Transition
  - XI. Discussion

## WATER PROTON ENVIRONMENT: A NEW WATER ANOMALY AT ATOMIC SCALE?

A. GIULIANI, M. A. RICCI, and F. BRUNI

Dipartimento di Fisica "E. Amaldi," Università degli Studi di Roma Tre, Via della Vasca Navale 84, 00146 Roma, Italy

## **CONTENTS**

- I. Introduction
- II. DINS Theory
- III. DINS Experimental Setup
- IV. Bulk Water at Ambient Pressure
- V. Water Under Pressure
- VI. Concluding Remarks

## POLYMORPHISM AND ANOMALOUS MELTING IN ISOTROPIC FLUIDS

## GIANPIETRO MALESCIO

Dipartimento di Fisica, Università degli Studi di Messina, Contrada Papardo, 98166 Messina, Italy

## **CONTENTS**

- I. Introduction
- II. Polymorphism and Anomalous Melting
- III. Interaction Model
- IV. Phase Diagram, Thermodynamic, Dynamic and Structural Properties References

## TRANSPORT AND DYNAMICS IN SUPERCOOLED CONFINED WATER

FRANCESCO MALLAMACE,<sup>1,2</sup> CARMELO CORSARO,<sup>1</sup> SOW-HSIN CHEN,<sup>2</sup> and H. EUGENE STANLEY<sup>3</sup>

<sup>1</sup>Dipartimento di Fisica and CNISM, Università di Messina, I-98166 Messina, Italy

<sup>2</sup>Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA <sup>3</sup>Center for Polymer Studies, Department of Physics, Boston University, Boston, MA 02215, USA

## CONTENTS

- I. Introduction
- II. Current Hypotheses
  - A. Selected Experimental and Simulation Results
  - B. Understanding "Static Heterogeneities"
  - C. Potentials with Two Characteristic Length Scales
  - D. Two Length Scales Potentials: Tractable Models
  - E. Understanding "Dynamic Heterogeneities"
  - F. Possible Significance of the Widom Line
- III. Methods for the Confined Water Dynamic Crossover
- IV. Recent Experiments on Confined Water
  - A. Nuclear Magnetic Resonance
  - B. Neutron Scattering
- V. The Breakdown of the Stokes-Einstein Relation
- VI. The LDL Phase and the Water Density Minimum
- VII. Specific Heat and the Glass Transition
  - A. Specific Heat Measurements in Glass Forming Systems
  - B. The Water Heat Capacity
- VIII. The NMR and the Configurational Heat Capacity
- IX. Concluding Remarks

## WATER AND BIOLOGICAL MACROMOLECULES

FRANCESCO MALLAMACE, 1,2 CARMELO CORSARO, 1 DOMENICO MALLAMACE, 3 H. EUGENE STANLEY, 4 and SOW-HSIN CHEN2

<sup>1</sup>Dipartimento di Fisica and CNISM, Università di Messina, I-98166 Messina, Italy
<sup>2</sup>Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
<sup>3</sup>Dipartimento di Scienze degli Alimenti e dell' Ambiente, Università di Messina, I-98166 Messina, Italy
<sup>4</sup>Center for Polymer Studies, Department of Physics, Boston University, Boston, MA 02215, USA

## **CONTENTS**

- I. Introduction
- II. The Two Dynamical Crossovers
- III. The Protein Glass Transition Crossover
  - A. Neutron Results
    - B. The Violation of the Stokes-Einstein Relation
    - C. The Simulation Results
    - D. About the FSC
- IV. High-Temperature Dynamic Crossover
  - A. Neutron Scattering and MD Simulation Results
  - B. NMR Results
- V. Conclusive Notes

## POLYAMORPHISM AND LIQUID-LIQUID PHASE TRANSITIONS IN AMORPHOUS SILICON AND SUPERCOOLED Al<sub>2</sub>O<sub>3</sub>-Y<sub>2</sub>O<sub>3</sub> LIQUIDS

PAUL F. MCMILLAN, <sup>1</sup> G. NEVILLE GREAVES, <sup>1,2</sup> MARK WILSON, <sup>3</sup> MARTIN C. WILDING, <sup>2</sup> and DOMINIK DAISENBERGER<sup>4</sup>

<sup>1</sup>Department of Chemistry, University College London, 20 Gordon Street, London WC1H 0AJ, UK <sup>2</sup>Centre for Advanced Functional Materials and Devices, Institute of Mathematics and Physical Sciences, University of Wales at Aberystwyth, Ceredigion SY23 3BZ, UK <sup>3</sup>Physical and Theoretical Chemistry Laboratory, Department of Chemistry, University of Oxford, South Parks Road, Oxford 0X1 3QZ, UK <sup>4</sup>1-185 (Zone 12), Diamond Light Source Ltd., Diamond House, Harwell Science Campus, Didcot, Oxfordshire, OX11 0DE, UK

#### CONTENTS

- I. Introduction
  - A. Anomalies in Melting Relations and Development of Two-State Liquid Models
  - B. Polyamorphism and Pressure-Induced Amorphization
  - C. Studies of PIA, Polyamorphism and LLPT in H2O
- II. Amorphous Si and Ge
  - A. Solid-State Polyamorphism Studies and the Case for a LLPT
  - B. Negative Melting Slopes, Two-State Models and Prediction of a LLPT for Si and Ge
  - C. X-Ray Scattering Measurements: Polyamorphism Versus Metastable Crystallization
- III. Al<sub>2</sub>O<sub>3</sub>-Y<sub>2</sub>O<sub>3</sub> Supercooled Liquids and Glasses
  - A. Early Observations and In Situ Levitation Studies
  - B. X-Ray and Neutron Scattering and Simulation Studies of Polyamorphic Glasses and Liquids
  - C. Polyamorphism, LLPT, and Metastable Crystallization in the Al<sub>2</sub>O<sub>3</sub>-Y<sub>2</sub>O<sub>3</sub> System
- IV. Conclusions



## **POLYAMORPHISM IN WATER\***

## **OSAMU MISHIMA**

National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

## **CONTENTS**

- I. Introduction
- II. Pressure-Induced Amorphization: The Discovery of HDA
- III. Transition Between LDA and HDA: The Discovery of Apparent Polyamorphism
- IV. Water's Liquid-Liquid Transition and Its Liquid-Liquid Critical Point
  - A. Experimental Problem
    - 1. Discontinuity of the LDA-HDA Transition
    - 2. Continuity Between HDA and Liquid Water
    - 3. My View on the Problem
  - B. The Location of LLT
  - C. The Location of LLCP
- V. Conclusion
- VI. Implications

# COMPUTER SIMULATIONS OF LIQUID SILICA: WATER-LIKE THERMODYNAMIC AND DYNAMIC ANOMALIES, AND THE EVIDENCE FOR POLYAMORPHISM

IVAN SAIKA-VOIVOD1 and PETER H. POOLE2

<sup>1</sup>Department of Physics and Physical Oceanography, Memorial University of Newfoundland, St. John's, NL, A1B 3X7, Canada

<sup>2</sup>Department of Physics, St. Francis Xavier University, Antigonish, NS, B2G 2W5, Canada

#### CONTENTS

- I. Introduction
- II. Simulations: Rigid-Ion Models of Silica
- III. Amorphous Solid Behavior
- IV. Water-Like Thermodynamic and Dynamic Anomalies
- V. Evidence for a Liquid-Liquid Phase Transition
- VI. Outlook



## POLYMORPHISM IN LATTICE MODELS

MARCIA M. SZORTYKA, <sup>1</sup> MAURICIO GIRARDI, <sup>2</sup> CARLOS E. FIORE, <sup>3</sup> VERA B. HENRIQUES, <sup>4</sup> and MARCIA C. BARBOSA <sup>5</sup>

 <sup>1</sup>Departamento de Física, Universidade Federal de Santa Catarina, Caixa Postal 476, 88010-970, Florianópolis, SC, Brazil
 <sup>2</sup>Universidade Federal de Santa Catarina, 88900-000, Araranguá, SC, Brazil
 <sup>3</sup>Departamento de Física, Universidade Federal do Paraná, Caixa Postal 19044, 81531 Curitiba, PR, Brazil

<sup>4</sup>Instituto de Física, Universidade de São Paulo, Caixa Postal 66318, 05315970, São Paulo, SP, Brazil

<sup>5</sup>Instituto de Física, Universidade Federal do Rio Grande do Sul, Caixa Postal 15051, 91501-970, Porto Alegre, RS, Brazil

#### **CONTENTS**

- I. Introduction
- II. Associating Lattice Gas in Two and Three Dimensions
- III. Bell-Lavis Water Model
- IV. Conclusions

## COOPERATIVE BOND ORDERING IN LIQUID: ITS LINK TO LIQUID POLYMORPHISM AND WATER-LIKE ANOMALIES

#### HAJIME TANAKA

Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan

#### **CONTENTS**

- I. Introduction
- II. Significance of Bond Orientational Ordering in Liquid
- III. Phenomenological Two-Order-Parameter Model of Liquid
  - A. Background
  - B. Local Bond Ordering Associated with the Formation of Locally Favored Structures
- IV. Liquid-Liquid Transition
  - A. Thermodynamics
  - B. Kinetics of LLT
  - C. Microscopy Observation of LLT in Molecular Liquids
- V. Thermodynamic and Kinetic Anomalies of Water-Type Liquids
  - A. What Makes Water so Different from Ordinary Liquids?
  - B. Thermodynamic Anomalies of Water-Type Liquids
  - C. Water-Type Atomic Liquids
  - D. Liquid-Liquid Transition in Water-Type Liquids
  - E. Glass-Forming Ability of Water
- VI. Summary and Open Questions

## STATISTICAL MECHANICAL APPROACH TO THE THERMODYNAMIC STABILITY OF CLATHRATE HYDRATES

#### HIDEKI TANAKA and MASAKAZU MATSUMOTO

Department of Chemistry, Graduate School of Natural Science and Technology, Okayama University, 3-1-1 Tsushima-naka, Kitaku, Okayama 700-8530, Japan

### CONTENTS

- I. Introduction
- II. Structure and Guest Species of Clathrate Hydrates
  - A. Structure of Host Water
  - B. Guest Molecules Encaged in Clathrate Hydrates
- III. Basic Theory
  - A. Prediction of Thermodynamic Stability of Clathrate Hydrate
  - B. Thermodynamic Variables and Ensembles for the Equilibrium of Clathrate Hydrates
  - C. Statistical Mechanical Foundation
  - D. vdWP Theory for Multiple Guest Components
- IV. Extension of the vdWP Theory
  - A. Conversion to Generalized Ensemble for High-Pressure Condition
  - B. Phase Equilibrium and the vdWP Theory for Multiple Occupation at High Pressure
  - C. vdWP Theory with a Reference State of the Fully Occupied Cages
  - D. vdWP Theory Under a Limited Amount of a Guest Species Highly Affinitive to Clathrate Hydrate
  - E. Cage Occupancy by Mean Field Approximation
- V. Calculation of Free Energy and Chemical Potential
  - A. Calculation of Free Energy of Solid and Liquid States and Free Energy of Cage Occupation
  - B. Free Energy of Cage Occupation Under the Original vdWP Assumption
  - C. Evaluation of the Free Energy for Clathrate Hydrates
- VI. Numerical Simulation for Estimation of Phase Equilibrium
  - A. GC/NPT Monte Carlo Simulations
  - B. Chemical Potential for Guest Fluid
- VII. Application to Thermodynamic Stability of Clathrate Hydrates
  - A. Chemical Potential of Ices and Empty Clathrate Hydrates

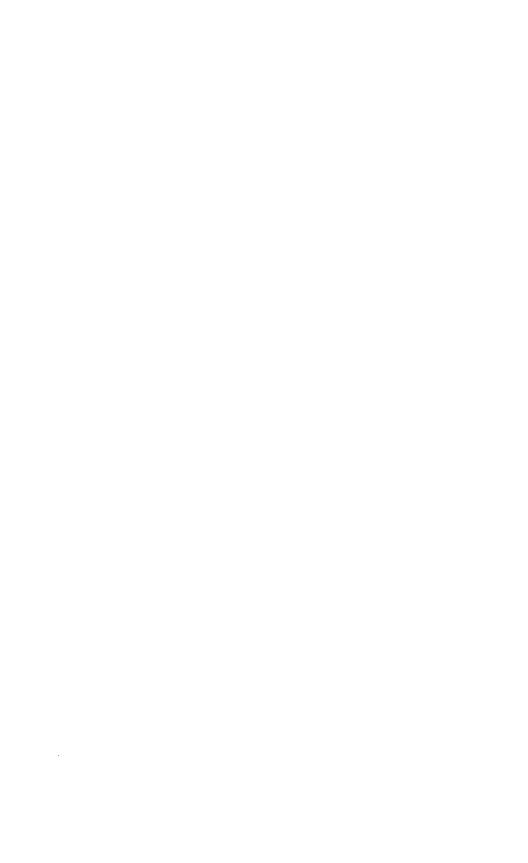
Liquid Polymorphism: Advances in Chemical Physics, Volume 152, First Edition.

Edited by H. Eugene Stanley.

© 2013 John Wiley & Sons, Inc. Published 2013 by John Wiley & Sons, Inc.

- B. Estimation of Stability at Low Pressures by the Extension of the vdWP Theory
- C. Thermodynamic Stability Combined with GC/NPT MC Simulation
- D. Estimation of Stability at High Pressures by the Extension of the vdWP Theory
- E. Structure Selectivity

VIII. Conclusion



## LIQUID-LIQUID PHASE TRANSITION IN SUPERCOOLED SILICON

VISHWAS V. VASISHT1 and SRIKANTH SASTRY1,2

<sup>1</sup> Theoretical Sciences Unit, Jawaharlal Nehru Centre for Advanced Scientific Research, Jakkur Campus, Bangalore 560 064, India.

<sup>2</sup> TIFR Centre for Interdisciplinary Sciences, Tata Institute of Fundamental Research, 21 Brundavan Colony, Narsingi, Hyderabad 500 075, India.

#### CONTENTS

- I. Introduction
- II. Early Work on Metastable Silicon
- III. Scenarios for Liquids Displaying Thermodynamic Anomalies
- IV. Recent Studies of Metastable Silicon
  - A. Experimental Studies
  - B. Simulation Studies: Phase Behavior, Structure, and Dynamics
    - 1. Liquid-Liquid Transition at Zero Pressure
    - 2. Liquid-Liquid Critical Point
    - 3. Phase Diagram
    - 4. Structural and Dynamical Properties
- V. Electronic Structure
- VI. Critical Assessment of Classical Simulation Results
- VII. Summary

## SIMILARITIES OF THE COLLECTIVE INTERFACIAL DYNAMICS OF GRAIN BOUNDARIES AND NANOPARTICLES TO GLASS-FORMING LIQUIDS

HAO ZHANG1 and JACK F. DOUGLAS2

<sup>1</sup>Department of Chemical and Materials Engineering, University of Alberta, AB T6G 2V4 Canada <sup>2</sup>Materials Science and Engineering Division, NIST, Gaithersburg MD, 20899 USA

## **CONTENTS**

- I. Introduction
- II. Cooperative Atomic Motion in Grain Boundaries
  - A. Grain Boundary Geometry and Simulation Model
  - B. Cooperative Particle Motion within the GB
  - C. Similarity of GB Mobility to Transport Properties of Glass-Forming Liquids
  - D. Cooperative Molecular Motion in GB and Glass-Forming Liquids
  - E. Comparison of the Characteristic Temperatures of GB and Glass-Forming Liquids
  - F. Comparative "Fragility" of GB and Glass-Forming Liquids
  - G. New Perspective on Nature of Applied Stress and Impurities on GB Dynamics
  - H. General Observations Regarding the Interfacial Dynamics of Grain Boundaries
- III. Cooperative Atomic Motion in the Interfaces of Nanoparticles
  - A. Simulations of Nanoparticle Interfacial Dynamics
  - B. Cooperative Atomic Motion on Nanoparticle Surface
  - C. Aging Phenomena in the Interfacial Dynamics of Nanoparticles
  - D. String Dynamics Accompanying NP Melting and Freezing
  - E. Influence of Metal Alloying on Nanoparticle Interfacial Dynamics
  - F. Conclusions Regarding the Interfacial Dynamics of Nanoparticles
- IV. Future Work and General Observations about Collective Atomic Motion References