

# Phase transition grade and microstructure of AdS black holes in massive gravity

Guan-Ru Li<sup>1</sup> , Guo-Ping Li<sup>2</sup>  and Sen Guo<sup>1,\*</sup> 

<sup>1</sup> Guangxi Key Laboratory for Relativistic Astrophysics, School of Physical Science and Technology, Guangxi University, Nanning 530004, People's Republic of China

<sup>2</sup> School of Physics and Astronomy, China West Normal University, Nanchong 637000, People's Republic of China

E-mail: [sguophys@126.com](mailto:sguophys@126.com)

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## Abstract

Considering that under the framework of the massive gravity theory, the interaction between the mass gravitons and Schwarzschild black hole (BH) could make it carry a scalar charge, the phase transition process caused by this scalar charge is investigated in this analysis. The phase transition grade and microstructure of those BHs are investigated from both macroscopic and microscopic points of view. From the macroscopic point of view, it is found that Ehrenfest equations are satisfied at the phase transition critical point, which implies that the phase transition grade of those BHs is second-order. Based on the BH molecules model and Landau continuous phase transition theory, the phase transition of those BHs from the microcosmic point of view is analyzed. The critical exponents obtained from the two perspectives are consistent. By investigating the Ruppeiner geometry, the microstructure feature of those BHs is revealed. These results suggest that the phase transition of BH in massive gravity is a standard second-order phase transition at the critical point, and the microscopic details of those BHs are different from the Reissner–Nordström AdS BH in standard Einstein gravity.

**Keywords:** phase transition grade, microstructure, massive gravity

(Some figures may appear in colour only in the online journal)

## 1. Introduction

Observation results of the gravitational wave of Laser-Interferometer Gravitational Wave-Observatory (LIGO) collaboration conform to the predictions of general relativity (GR) [1].

\* Author to whom any correspondence should be addressed.

# Microstructure And Phase Transition

**Tung-sheng Yen, Joseph Adam Pask**



## **Microstructure And Phase Transition:**

**Microstructure and Phase Transition** David Kinderlehrer, Richard James, Mitchell Luskin, Jerry L. Ericksen, 2012-12-06 This IMA Volume in Mathematics and its Applications MICROSTRUCTURE AND PHASE TRANSITION is based on the proceedings of a workshop which was an integral part of the 1990 91 IMA program on Phase Transitions and Free Boundaries We thank R Fosdick M E Gurtin W M Ni and L A Peletier for organizing the year long program and especially D Kinderlehrer R James M Luskin and J Ericksen for organizing the meeting and editing these proceedings We also take this opportunity to thank those agencies whose financial support made the workshop possible the Army Research Office and the National Science Foundation A vner Friedman Willard Miller Jr PREFACE Much of our traditional knowledge of materials and processes is achieved by observation and analysis of small departures from equilibrium Many materials especially modern alloys ceramics and their composites experience not only larger but more dramatic changes such as the occurrence of phase transitions and the creation of defect structures when viewed at the microscopic scale How is this observed how can it be interpreted and how does it influence macroscopic behavior These are the principle concerns of this volume which constitutes the proceedings of an IMA workshop dedicated to these issues [Phase Transitions in Materials](#) Brent Fultz, 2020-05-14 The new edition of this popular textbook provides a fundamental approach to phase transformations and thermodynamics of materials Explanations are emphasised at the level of atoms and electrons and it comprehensively covers the classical topics from classical metallurgy to nanoscience and magnetic phase transitions The book has three parts covering the fundamentals of phase transformations the origins of the Gibbs free energy and the major phase transformations in materials science A fourth part on advanced topics is available online Much of the content from the first edition has been expanded notably precipitation transformations in solids heterogeneous nucleation and energy entropy and pressure Three new chapters have been added to cover interactions within microstructures surfaces and solidification Containing over 170 end of chapter problems it is a valuable companion for graduate students and researchers in materials science engineering and applied physics **Dispersion Stability, Microstructure and Phase Transition of Anisotropic Nanodiscs** Ravi Kumar Pujala, 2014-06-03 This thesis explores the dispersion stability microstructure and phase transitions involved in the nanoclay system It describes the recently discovered formation of colloidal gels via two routes the first is through phase separation and second is by equilibrium gelation and includes the first reported experimental observation of a system with high aspect ratio nanodiscs The phase behavior of anisotropic nanodiscs of different aspect ratio in their individual and mixed states in aqueous and hydrophobic media is investigated Distinct phase separation equilibrium fluid and equilibrium gel phases are observed in nanoclay dispersions with extensive aging The work then explores solution behavior gelation kinetics aging dynamics and temperature induced ordering in the individual and mixed states of these discotic colloids Anisotropic ordering dynamics induced by a water air interface waiting time and temperature in these dispersions

were studied in great detail along with aggregation behavior of nanoplatelets in hydrophobic environment of alcohol solutions

**European Congress of Mathematics** Antal Balog, Domokos Szász, András Recski, Gyula Katona, 1998-07-21 This is the second volume of the proceedings of the second European Congress of Mathematics Volume I presents the speeches delivered at the Congress the list of lectures and short summaries of the achievements of the prize winners Together with volume II it contains a collection of contributions by the invited lecturers Finally volume II also presents reports on some of the Round Table discussions This two volume set thus gives an overview of the state of the art in many fields of mathematics and is therefore of interest to every professional mathematician Contributors Vol I N Alon L Ambrosio K Astala R Benedetti Ch Bessenrodt F Bethuel P Björnstad E Bolthausen J Bricmont A Kupiainen D Burago L Caporaso U Dierkes I Dynnikov L H Eliasson W T Gowers H Hedenmalm A Huber J Kaczorowski J Kollár D O Kramkov A N Shiryaev C Lescop R M Ruzhansky Vol II J Matousek D McDuff A S Merkurjev V Milman Sturmfels T Nowicki E Olivieri E Scoppola V P Platonov J P Schell L Polterovich L Pyber N Simányi J P Solovej A Stipsicz G Tardos J P Tignol A P Veselov E Zuazua

**Phase Transitions in Materials** Brent Fultz, 2020-05-14 This book explains the thermodynamics and kinetics of most of the important phase transitions in materials science It is a textbook so the emphasis is on explanations of phenomena rather than a scholarly assessment of their origins The goal is explanations that are concise clear and reasonably complete The level and detail are appropriate for upper division undergraduate students and graduate students in materials science and materials physics The book should also be useful for researchers who are not specialists in these fields The book is organized for approximately sequential coverage in a graduate level course The four parts of the book serve different purposes however and should be approached differently

**Variational Methods for Crystalline Microstructure - Analysis and Computation** Georg Dolzmann, 2004-10-23 Phase transformations in solids typically lead to surprising mechanical behaviour with far reaching technological applications The mathematical modeling of these transformations in the late 80s initiated a new field of research in applied mathematics often referred to as mathematical materials science with deep connections to the calculus of variations and the theory of partial differential equations This volume gives a brief introduction to the essential physical background in particular for shape memory alloys and a special class of polymers nematic elastomers Then the underlying mathematical concepts are presented with a strong emphasis on the importance of quasiconvex hulls of sets for experiments analytical approaches and numerical simulations

*Analysis of Gd<sub>5</sub>(Si<sub>2</sub>Ge<sub>2</sub>) Microstructure and Phase Transition* John Scott Meyers, 2002 The material Gd<sub>5</sub>Si<sub>x</sub>Ge<sub>1-x</sub> with  $x \approx 2$  was investigated using electron microscopy The material possesses a complex crystallographic structure and undergoes a unique reversible transformation at low temperatures and an irreversible high temperature transformation Alloys produced by induction melting and arc melting were examined and the phases identified The results of SEM and TEM studies of the high room and low temperature microstructures are reported Direct observation of the transformation with a discussion on the mechanism of the reversible

low temperature phase transformation is detailed      **The Dynamical Creation of Microstructure in Material Phase Transitions** Pieter J. Swart,1991      **Phase Transition and Microstructure of Equiatomic RhTi** Chris Charles Walton,1992      **Microstructure and Phase Transitions in Solids** C. Davini,1995      **Microstructure and Properties of Ceramic Materials** Tung-sheng Yen,Joseph Adam Pask,1984      *Plasticity and Beyond* Jörg Schröder,Klaus Hackl,2013-09-20 The book presents the latest findings in experimental plasticity crystal plasticity phase transitions advanced mathematical modeling of finite plasticity and multi scale modeling The associated algorithmic treatment is mainly based on finite element formulations for standard local approach as well as for non standard non local approach continua and for pure macroscopic as well as for directly coupled two scale boundary value problems Applications in the area of material design processing are covered ranging from grain boundary effects in polycrystals and phase transitions to deep drawing of multiphase steels by directly taking into account random microstructures      *Japanese Journal of Applied Physics* ,2007

*Solidification Processes and Microstructures* Michel Rappaz,Christoph Beckermann,Rohit Trivedi,2004-03 Papers from a March 2004 symposium describe recent work in solidification processes and microstructures in the areas of mushy zone dynamics rapid solidification and phase field modeling Some specific topics include kinetics of dendritic mushy zones anisotropy effects in lamellar eutectic growth network modeling of liquid metal transport in solidifying aluminum alloys and the topology of coarsened microstructures Other topics include diffuse solid liquid interfaces and solute trapping phase selection transitions during undercooled melt solidification dendritic growth in confined spaces the influence of foreign particles in the formation of polycrystalline solidification patterns and a cellular automaton for growth of solutal dendrites Annotation 2004 Book News Inc Portland OR booknews com      **Heat Transfer: Soviet Research** ,1973      **Scientific and Technical Aerospace Reports** ,1992      **Advances in High-Tc Superconductors** John J. Pouch,1993 This book points out the most recent developments in the young and exciting field of high temperature superconductors The contributed papers cover a large variety of different aspects of these materials such as physical and chemical properties fabrication and processing technology probing techniques and device technology      Materials Science and Engineering Technology Zhang Mei,2014-06-30 Selected peer reviewed papers from the 2014 International Conference on Materials Science and Engineering Technology MSET 2014 June 28 29 2014 Shanghai China      **Phase Transitions in Crystals: the Analysis of Microstructure** University of Minnesota. Institute for Mathematics and Its Applications,D. Kinderlehrer,1987      Advanced Materials and Engineering Materials IX Peng Sheng Wei,2020-09-02 Selected peer reviewed full text papers from the 9th International Conference on Advanced Materials and Engineering Materials ICAMEM 2020 Selected peer reviewed papers from the 9th International Conference on Advanced Materials and Engineering Materials ICAMEM 2020 July 3 5 2020 Bangkok Thailand

## Adopting the Tune of Appearance: An Mental Symphony within **Microstructure And Phase Transition**

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