Gravitational waves from phase transitions in scale invariant models

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ABSTRACT: We investigate the properties of the gravitational waves (GW) generated during a strongly first order electroweak phase transition (EWPT) in models with the classical scale invariance (CSI). Here, we distinguish two parameter space regions that correspond to the cases of (1) light dilaton and (2) purely radiative Higgs mass (PRHM). In the CSI models, the dilaton mass, or the Higgs mass in the PRHM case, in addition to some triple scalar couplings are fully triggered by the radiative corrections (RCs). In order to probe the RC effects on the EWPT strength and on the GW spectrum, we extend the standard model by a real singlet to assist the electroweak symmetry breaking and an additional scalar field Q with multiplicity N_Q and mass m_Q. After imposing all theoretical and experimental constraints, we show that a strongly first order EWPT with detectable GW spectra can be realized for the two cases of light dilaton and PRHM. We also show the corresponding values of the relative enhancement of the cross section for the di-Higgs production process, which is related to the triple Higgs boson coupling. We obtain the region in which the GW spectrum can be observed by different future experiments such as LISA and DECIGO. We also show that the scenarios (1) and (2) can be discriminated by future GW observations and measurements of the di-Higgs productions at future colliders.

KEYWORDS: Cosmology of Theories BSM, Multi-Higgs Models, Phase Transitions in the Early Universe

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Models of Phase Transitions Augusto Visintin,1996-12-01 What do you call work Why ain t that work Tom resumed his whitewashing and answered carelessly Well lI1a he it is and maybe it aill t All I know is it suits Tom Sawvc Oil CO lll IIOW Will do not mean to let 011 that you like it The brush continued to move Likc it Well I do not see wlzy I oughtn t to like it Does a hoy get a chance to whitewash a fence every day That put the thing ill a Ilew light Ben stopped nibhling the apple From Mark Twain s Adventures of Tom Sawyer Chapter II Mathematics can put quantitative phenomena in a new light in turn applications may provide a vivid support for mathematical concepts This volume illustrates some aspects of the mathematical treatment of phase transitions namely the classical Stefan problem and its generalizations The in tended reader is a researcher in application oriented mathematics An effort has been made to make a part of the book accessible to beginners as well as physicists and engineers with a mathematical background Some room has also been devoted to illustrate analytical tools This volume deals with research I initiated when I was affiliated with the Istituto di Analisi Numerica del C N R in Pavia and then continued at the Dipartimento di Matematica dell Universita di Trento It was typeset by the author in plain TEX   **Models of Phase Transitions** Augusto Visintin,2011-10-29   *Continuum Models for Phase Transitions and Twinning in Crystals* Mario Pitteri,G. Zanzotto,2002-06-27 Continuum Models for Phase Transitions and Twinning in Crystals presents the fundamentals of a remarkably successful approach to crystal thermomechanics Developed over the last two decades it is based on the mathematical theory of nonlinear thermoelasticity in which a new viewpoint on material symmetry motivated by molecular theories plays a c   Mathematical Methods and Models in Phase Transitions Alain Miranville,2005 The modelling and the study of phase transition phenomena are capital issues as they have essential applications in material sciences and in biological and industrial processes We can mention e g phase separation in alloys ageing of materials microstructure evolution crystal growth solidification in complex alloys surface diffusion in the presence of stress evolution of the surface of a thin flow in heteroepitaxial growth motion of voids in interconnects in integrated circuits treatment of airway closure disease by surfactant injection fuel injection fire extinguishers etc This book consists of 11 contributions from specialists in the mathematical modelling and analysis of phase transitions The content of these contributions ranges from the modelling to the mathematical and numerical analysis Furthermore many numerical simulations are presented Finally the contributors have tried to give comprehensive and accurate reference lists This book should thus serve as a reference book for researchers interested in phase transition phenomena   *Mathematical Methods and Models in Phase Transitions* ,2006   *Dissipative Phase Transitions* Pierluigi Colli,Nobuyuki Kenmochi,Jurgen Sprekels,2006-03-06 Phase transition phenomena arise in a variety of relevant real world situations such as melting and freezing in a solid liquid system evaporation solid solid phase transitions in shape memory alloys combustion crystal growth damage in elastic materials glass formation phase transitions in polymers and plasticity The practical interest of such phenomenology is evident and has deeply influenced the

technological development of our society stimulating intense mathematical research in this area This book analyzes and approximates some models and related partial differential equation problems that involve phase transitions in different contexts and include dissipation effects   Nonequilibrium Phase Transitions in Lattice Models Joaquin Marro,Ronald Dickman,1999-05-06 This book provides an introduction to nonequilibrium statistical physics via lattice models Beginning with an introduction to the basic driven lattice gas the early chapters discuss the relevance of this lattice model to certain natural phenomena examining simulation results in detail Later chapters discuss absorbing state transitions and examine a variety of systems subject to dynamic disorder The book discusses the effects of multiparticle rules nonunique absorbing states and conservation laws as well as the use of methods such as mean field theory Monte Carlo simulation and the concept of universality It also includes detailed references and examples using simple respresentations of nature to describe real systems   **Statistical Mechanics of Phase Transitions** J. M. Yeomans,1992-05-07 The book provides an introduction to the physics which underlies phase transitions and to the theoretical techniques currently at our disposal for understanding them It will be useful for advanced undergraduates for post graduate students undertaking research in related fields and for established researchers in experimental physics chemistry and metallurgy as an exposition of current theoretical understanding Recent developments have led to a good understanding of universality why phase transitions in systems as diverse as magnets fluids liquid crystals and superconductors can be brought under the same theoretical umbrella and well described by simple models This book describes the physics underlying universality and then lays out the theoretical approaches now available for studying phase transitions Traditional techniques mean field theory series expansions and the transfer matrix are described the Monte Carlo method is covered and two chapters are devoted to the renormalization group which led to a break through in the field The book will be useful as a textbook for a course in Phase Transitions as an introduction for graduate students undertaking research in related fields and as an overview for scientists in other disciplines who work with phase transitions but who are not aware of the current tools in the armoury of the theoretical physicist Introduction Statistical mechanics and thermodynamics Models Mean field theories The transfer matrix Series expansions Monte Carlo simulations The renormalization group Implementations of the renormalization group   **Application of Integrable Systems to Phase Transitions** C.B. Wang,2013-07-20 The eigenvalue densities in various matrix models in quantum chromodynamics QCD are ultimately unified in this book by a unified model derived from the integrable systems Many new density models and free energy functions are consequently solved and presented The phase transition models including critical phenomena with fractional power law for the discontinuities of the free energies in the matrix models are systematically classified by means of a clear and rigorous mathematical demonstration The methods here will stimulate new research directions such as the important Seiberg Witten differential in Seiberg Witten theory for solving the mass gap problem in quantum Yang Mills theory The formulations and results will benefit researchers and students in the fields of

phase transitions integrable systems matrix models and Seiberg Witten theory   Phase Transitions For Beginners Sergei M Stishov,2018-10-02 Written by an experimentalist famous for his discovery of stishovite with vast experience in phase transition studies this book is devoted to a description of the continuous and discontinuous phase transitions It includes chapters outlining the Van der Waals model hard sphere and soft sphere models of melting scaling phenomena renormgroup approach to phase transitions and experimental examples to illustrate various phase transitions Unlike conventional books covering the same topic this is meant for undergraduate students and experimentalists to understand basic concepts in the physics of phase transitions   *Phase Transitions of Simple Systems* Boris M. Smirnov,Stephen R. Berry,2007-10-24 Thermodynamic concepts of aggregate states and their phase transitions veloped during the 19th Century and are now the basis of our contem rary understanding of these phenomena Thermodynamics gives an universal macroscopic description of the equilibrium properties of phase transitions dependent of the detailed nature of the substances However understanding the nature of phase transitions at the microscopic level requires a di erent approach one that takes into account the speci cs of the interparticle int actions In this book we lay the groundwork that connects the microscopic phenomena underlying phase changes with the macroscopic picture but in a somewhat restricted way We deal only with systems in which electronic excitations are not important only with atomic systems and only with mogeneous systems We also restrict our analysis to systems in which only pairwise interactions need be included and in many parts of the treatment to systems in which one need consider only the interactions between nearest neighbor atoms In establishing these restrictions we can be guided by the solid and liquid states of inert gases and the phase transitions between them althoughthesubsequentanalysisisrelevantandapplicableforaseriesofother physical systems To study the behavior of a system of many interacting identical par cles we work extensively with its potential energy surface PES a surface in a many dimensional space whose independent variables are the monomer coordinates or some transformation thereof A central property of any m tidimensional PES is its large number of local minima   Phase Transitions: A Brief Account With Modern Applications Moshe Gitterman,Vivian (Haim) Halpern,2004-08-03 This book presents a short fairly simple course on the basic theory of phase transitions and its modern applications In physics these applications include such modern developments as Bose Einstein condensation of atoms high temperature superconductivity and vortices in superconductors while in other fields they include small world phenomena and scale free systems such as stock markets and the Internet The advantage of treating all these topics together lies in showing their connection with one another and with the general theory of phase transitions   PDEs and Continuum Models of Phase Transitions Michel Rascle,Denis Serre,Marshall Slemrod,2014-08-23 The study of phase transitions is one of the fundamental problems of physics The goal of this seminar was to understand better the spectacular progress made recently in constructing continuum models Concentrating on a few examples such as the microstructure of crystals defects in liquid crystals and liquid vapor interfaces several key points are described for

example the structure and evolution of the interfaces regularization via interfacial energy and equilibrium theories The mathematical treatment of these questions involves large oscillation theories Young s measures compensated compactness spectral theory admissibility of shock waves long time behavior of dynamical systems high order perturbations group actions solitons and others **Phase Transitions** Ricard Solé,2011-07-25 Phase transitions changes between different states of organization in a complex system have long helped to explain physics concepts such as why water freezes into a solid or boils to become a gas How might phase transitions shed light on important problems in biological and ecological complex systems Exploring the origins and implications of sudden changes in nature and society Phase Transitions examines different dynamical behaviors in a broad range of complex systems Using a compelling set of examples from gene networks and ant colonies to human language and the degradation of diverse ecosystems the book illustrates the power of simple models to reveal how phase transitions occur Introductory chapters provide the critical concepts and the simplest mathematical techniques required to study phase transitions In a series of example driven chapters Ricard Sol shows how such concepts and techniques can be applied to the analysis and prediction of complex system behavior including the origins of life viral replication epidemics language evolution and the emergence and breakdown of societies Written at an undergraduate mathematical level this book provides the essential theoretical tools and foundations required to develop basic models to explain collective phase transitions for a wide variety of ecosystems *Mathematical Models in Phase Transitions* Hans Wilhelm Alt,Paul C. Fife,1995 **Elliptic Systems of Phase Transition Type** Nicholas D. Alikakos,Giorgio Fusco,Panayotis Smyrnelis,2019-01-21 This book focuses on the vector Allen Cahn equation which models coexistence of three or more phases and is related to Plateau complexes non orientable objects with a stratified structure The minimal solutions of the vector equation exhibit an analogous structure not present in the scalar Allen Cahn equation which models coexistence of two phases and is related to minimal surfaces The 1978 De Giorgi conjecture for the scalar problem was settled in a series of papers Ghoussoub and Gui 2d Ambrosio and Cabr 3d Savin up to 8d and del Pino Kowalczyk and Wei counterexample for 9d and above This book extends in various ways the Caffarelli C rdoba density estimates that played a major role in Savin s proof It also introduces an alternative method for obtaining pointwise estimates Key features and topics of this self contained systematic exposition include Resolution of the structure of minimal solutions in the equivariant class a for general point groups and b for general discrete reflection groups thus establishing the existence of previously unknown lattice solutions Preliminary material beginning with the stress energy tensor via which monotonicity formulas and Hamiltonian and Pohozaev identities are developed including a self contained exposition of the existence of standing and traveling waves Tools that allow the derivation of general properties of minimizers without any assumptions of symmetry such as a maximum principle or density and pointwise estimates Application of the general tools to equivariant solutions rendering exponential estimates rigidity theorems and stratification results This monograph is addressed to readers beginning from the graduate level with an

interest in any of the following differential equations ordinary or partial nonlinear analysis the calculus of variations the relationship of minimal surfaces to diffuse interfaces or the applied mathematics of materials science   **Phase Transitions and Critical Phenomena** ,2000-09-15 The field of phase transitions and critical phenomena continues to be active in research producing a steady stream of interesting and fruitful results No longer an area of specialist interest it has acquired a central focus in condensed matter studies The major aim of this serial is to provide review articles that can serve as standard references for research workers in the field and for graduate students and others wishing to obtain reliable information on important recent developments The two review articles in this volume complement each other in a remarkable way Both deal with what might be called the modern geometricapproach to the properties of macroscopic systems The first article by Georgii et al describes how recent advances in the application ofgeometric ideas leads to a better understanding of pure phases and phase transitions in equilibrium systems The second article by Alava et al deals with geometrical aspects of multi body systems in a hands on way going beyond abstract theory to obtain practical answers Thecombination of computers and geometrical ideas described in this volume will doubtless play a major role in the development of statisticalmechanics in the twenty first century   **Quantum Phase Transitions** Subir Sachdev,2001-04-23 Quantum Phase Transitions is the first book to describe in detail the fundamental changes that can occur in the macroscopic nature of matter at zero temperature due to small variations in a given external parameter The subject plays a central role in the study of the electrical and magnetic properties of numerous important solid state materials The author begins by developing the theory of quantum phase transitions in the simplest possible class of non disordered interacting systems the quantum Ising and rotor models Particular attention is paid to their non zero temperature dynamic and transport properties in the vicinity of the quantum critical point Several other quantum phase transitions of increasing complexity are then discussed and clarified Throughout the author interweaves experimental results with presentation of theoretical models and well over 500 references are included The book will be of great interest to graduate students and researchers in condensed matter physics
   Mathematical Models for Phase Change Problems J.F. Rodriques,1989-09-01   **Two Mean-field Theory Models of Phase Transitions** Johann Christian Schön,1988

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Table of Contents Models Of Phase Transitions

1. Understanding the eBook Models Of Phase Transitions
    - The Rise of Digital Reading Models Of Phase Transitions
    - Advantages of eBooks Over Traditional Books
2. Identifying Models Of Phase Transitions
    - Exploring Different Genres
    - Considering Fiction vs. Non-Fiction
    - Determining Your Reading Goals
3. Choosing the Right eBook Platform
    - Popular eBook Platforms
    - Features to Look for in an Models Of Phase Transitions
    - User-Friendly Interface
4. Exploring eBook Recommendations from Models Of Phase Transitions
    - Personalized Recommendations
    - Models Of Phase Transitions User Reviews and Ratings
    - Models Of Phase Transitions and Bestseller Lists
5. Accessing Models Of Phase Transitions Free and Paid eBooks
    - Models Of Phase Transitions Public Domain eBooks
    - Models Of Phase Transitions eBook Subscription Services
    - Models Of Phase Transitions Budget-Friendly Options

- Interactive and Gamified eBooks

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