

Phase Diagram and Commensurate-Incommensurate Transitions in the Phase Field Crystal Model with an External Pinning Potential

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We study the phase diagram and the commensurate-incommensurate transitions in a phase field model of a two-dimensional crystal lattice in the presence of an external pinning potential. The model allows for both elastic and plastic deformations and provides a continuum description of lattice systems, such as for adsorbed atomic layers or two-dimensional vortex lattices. Analytically, a mode expansion analysis is used to determine the ground states and the commensurate-incommensurate transitions in the model as a function of the strength of the pinning potential and the lattice mismatch parameter. Numerical minimization of the corresponding free energy shows good agreement with the analytical predictions and provides details on the topological defects in the transition region. We find that for small mismatch the transition is of first-order, and it remains so for the largest values of mismatch studied here. Our results are consistent with results of simulations for atomistic models of adsorbed overlayers.

PACS numbers: 64.60.Cn Order-disorder transformations; statistical mechanics of model systems, 64.70.Rh Commensurate-incommensurate transitions, 68.43.De Statistical mechanics of adsorbates, 05.40.-a Fluctuation phenomena, random processes, noise, and Brownian motion

I. INTRODUCTION

In nature there exist many modulated structures which possess two or more competing length scales. Such systems often exhibit commensurate-incommensurate (CI) phase transitions [1, 2], which are characterized by structural changes induced by competition between these different scales. Systems in this class that have received intense attention for many years include spin-density-waves [3, 4] in Cr and charge-density-wave systems [5] *e.g.* in "blue bronze". They are characterized by an order parameter (*e.g.*, charge or spin density) that is modulated in space with a given wave vector q . In these systems the transition from a commensurate (C) state to an incommensurate (I) state is controlled by temperature and interaction with defects of the lattice [6]. Other systems of interest are materials which exhibit magnetic phase with spiral-like structures [7, 8]. Finally, vortex lattices in superconducting films with pinning centers [9] and weakly adsorbed monolayers [10, 11] on a substrate comprise a 2D realization of systems exhibiting CI transitions. In these systems the interparticle interactions are minimized by a configuration with a lattice constant a , while the substrate-adsorbed monolayer interaction is minimized by a configuration with lattice constant b usually incommensurate with a .

The simplest theoretical model for a CI transition is the 1D Frenkel-Kontorova (FK) model [12, 13]. It consists of a chain of particles interconnected by springs, representing an adsorbate layer, and placed in a periodic potential describing the effects of a substrate. The potential energy of a such system is given by

$$U = \sum_n \left[\frac{\lambda}{2} (x_{n+1} - x_n - a)^2 + V(x_n) \right], \quad (1)$$

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Table of Contents Special Ibue On Incommensurate Phase Transitions

1. Understanding the eBook Special Ibue On Incommensurate Phase Transitions
 - The Rise of Digital Reading Special Ibue On Incommensurate Phase Transitions
 - Advantages of eBooks Over Traditional Books
2. Identifying Special Ibue On Incommensurate 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 Special Ibue On Incommensurate Phase Transitions
 - User-Friendly Interface
4. Exploring eBook Recommendations from Special Ibue On Incommensurate Phase Transitions
 - Personalized Recommendations
 - Special Ibue On Incommensurate Phase Transitions User Reviews and Ratings
 - Special Ibue On Incommensurate Phase Transitions and Bestseller Lists

5. Accessing Special Ibue On Incommensurate Phase Transitions Free and Paid eBooks
 - Special Ibue On Incommensurate Phase Transitions Public Domain eBooks
 - Special Ibue On Incommensurate Phase Transitions eBook Subscription Services
 - Special Ibue On Incommensurate Phase Transitions Budget-Friendly Options
6. Navigating Special Ibue On Incommensurate Phase Transitions eBook Formats
 - ePub, PDF, MOBI, and More
 - Special Ibue On Incommensurate Phase Transitions Compatibility with Devices
 - Special Ibue On Incommensurate Phase Transitions Enhanced eBook Features
7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Special Ibue On Incommensurate Phase Transitions
 - Highlighting and Note-Taking Special Ibue On Incommensurate Phase Transitions
 - Interactive Elements Special Ibue On Incommensurate Phase Transitions
8. Staying Engaged with Special Ibue On Incommensurate Phase Transitions
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Special Ibue On Incommensurate Phase Transitions
9. Balancing eBooks and Physical Books Special Ibue On Incommensurate Phase Transitions
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Special Ibue On Incommensurate Phase Transitions
10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
11. Cultivating a Reading Routine Special Ibue On Incommensurate Phase Transitions
 - Setting Reading Goals Special Ibue On Incommensurate Phase Transitions
 - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Special Ibue On Incommensurate Phase Transitions
 - Fact-Checking eBook Content of Special Ibue On Incommensurate Phase Transitions
 - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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