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Two-Dimensional Melting of Hexatic Magnetic Bubble Arrays

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Abstract: We report experimental observations of a continuous hexatic to liquid melting transition as a function of density in two-dimensional bubble arrays. At higher densities away from the transition we see a hexatic glass.

Introduction

Melting in two-dimensional systems can occur via the unbinding of point defects, as Kosterlitz and Thouless first demonstrated [1]. Building on this idea, Halperin and Nelson suggested that melting in two-dimensional solids occurs via two second order transitions driven by topological defects [2]. A continuous transition mediated by the unbinding of dislocation pairs transforms the crystalline phase characterized by long range orientational order and quasi-long range translational order into a hexatic phase characterized by quasi-long range orientational order and short range translational order. A second continuous transition at which dislocations unbind into disclinations transforms the hexatic into an isotropic liquid characterized by short range translational and orientational order. Young independently studied the crystal to hexatic transition [3]. Recently, Chudnovsky has suggested that the crystal to hexatic transition is absent in the presence of microscopic disorder, and a hexatic glass rather than a crystalline solid is the most ordered state [4]. Most experiments that study this transition, with notable exceptions [5-7], are limited by the inability to directly observe the arrays and study defect dynamics. Computational studies that permit such observations are limited by small numbers of particles, periodic boundary conditions and short equilibration times.

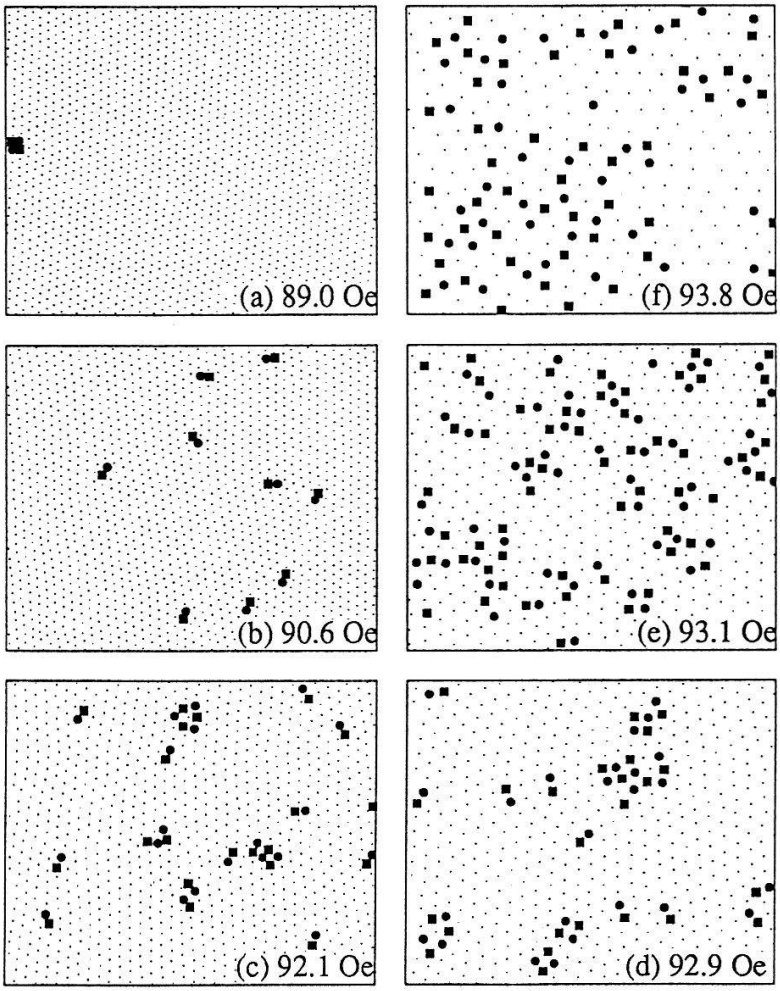

Figure 1. Overview of the melting transition: sections of processed images at the values of H_B indicated. The dots correspond to bubble centers. The black squares and circles represent bubbles with five and seven nearest neighbours respectively in the hexagonal lattice. Black circle - square disclination pairs correspond to edge dislocations.

Experiment

Magnetic bubbles in thin films of garnet form an experimentally accessible system to study

the process of melting in two-dimensions [8]. The bubbles are viewed directly using optical microscopy and digital imaging techniques. We begin this experiment by focussing on a single crystallite within a polycrystalline bubble lattice at H_B = 85 Oe, where H_B is the applied magnetic field opposed to the magnetization of the bubbles. The bubble density is slowly decreased by incrementing H_B in small steps from 85 Oe to 95 Oe. Each step results in the collapse of a few bubbles distributed uniformly over the lattice. The vacancies created immediately relax into dislocations. These dislocations are allowed to equilibrate for 30 minutes, after which images of the lattice are recorded. Topological defects and bond information are obtained from Voronoi constructions on the bubble centers determined from the recorded images. The bubble radius (3.3 μm) and the film thickness (7.8 μm) are smaller than the lattice spacings (17 μm to 47 μm) over the range of H_B used in this experiment. Therefore the bubble-bubble interaction can be approximated well by a dipole-dipole interaction ($1/r^3$). The bubble radius, and hence the bubble dipole moment, does not change appreciably from bubble to bubble and varies little with H_B over the range used.

In Fig. 1 (a) to 1 (f) the melting transition is summarized by sections of a series of processed images at the values of H_B indicated. Figure 1 (a) displays a hexatic glass that has short range translational order (~7a, where a is the lattice spacing) and long range orientational order. At this density the lattice has very few dislocation. Translational order is limited by microscopic roughness present in the garnet, and not by dislocations. The mobilities of the dislocations present are very low indicating that the system is glassy. The decrease in bubble density between Fig. 1 (a) and Fig. 1 (b) is accompanied by an increase in the dislocation concentration and mobility. The lattice in Fig. 1 (b) has a gas of dislocations and corresponds to a hexatic with short range translational order (~5a) limited by the dislocations, and quasi-long range orientational order (~100 a). The lattice in Fig. 1 (c) has properties similar to the one in Fig. 1 (b), and the dislocation begin to form simple clusters. These clusters evolve and rearrange continuously, and they do not stabilize and grow as in first order transitions. These transient clusters are larger in size in Fig. 1 (d). The dislocation mobility increases dramatically in Fig. 1 (d), and we begin to see thermal excitation of virtual dislocation pairs and dislocation rearrangement events on short time scales indicating that the system is near equilibrium. In Fig. 1 (e) the clusters begin to join and percolate across the system. A few dissociated disclinations can be identified. In Fig. 1 (f) the system is a liquid with both translational and orientational correlation lengths of ~1a. Here isolated clusters are no longer present, and disclination pairs cannot be identified. The hexatic (Fig 1 (b) and 1 (c)) to liquid (Fig. 1 (f)) phase transition occurring over Fig. 1 (d) and 1 (e) was found to be continuous from observations made in the presence of a linear spatial gradient in H_B.

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