

# This Week's Citation Classic

Nelson D R & Halperin B I. Dislocation-mediated melting in two dimensions.

*Phys. Rev. B—Condensed Matter* 19:2457-84. 1979. [Lyman Laboratory of Physics.

Harvard University, Cambridge, MA.]

A theory of dislocation-mediated melting in two dimensions is described in detail, with an emphasis on results for triangular lattices. The transition from solid to liquid takes place in two steps with increasing temperatures. Dissociation of dislocation pairs first drives a transition out of a low-temperature solid phase. This transition is into a "liquid-crystal" phase characterized by exponential decay of translational order, but power-law decay of sixfold orientational order. Dissociation of disclination pairs at a higher temperature then produces an isotropic fluid. [The *SC<sup>B</sup>* indicates that this paper has been cited in more than 580 publications.]

building on ideas due primarily to J.M. Kosterlitz and D.J. Thouless.<sup>4</sup> These authors had suggested that classical melting in thin films could proceed via an unbinding of pairs of defects called dislocations. Upon exploring this idea further, we found, to our surprise, that crystals must then melt in two separate stages, as first the translational and then the orientational symmetries which characterize liquids are restored with increasing temperature. Although dislocations do unbind, a second unbinding at higher temperatures of orientational disclination defects is necessary to complete the melting process. The disclination pairs necessary to produce an isotropic liquid are contained in the dislocation cores. The latent heat associated with the usual first order crystal-to-liquid transition is spread out over an entire intermediate phase. Because the new phase retains the sixfold orientational symmetry of the triangular crystal from which it melted, we called it a "hexatic liquid crystal." We also calculated the critical indices of the continuous phase transitions which separated the hexatic from the low-temperature crystal and the high-temperature liquid in our model.

An incorrect sign of the angular interaction term between dislocations printed in a famous book on dislocation theory led to an error in our initial calculation of one of these indices.<sup>5</sup> This calculation was done correctly and independently by Peter Young,<sup>6</sup> who did not realize, however, that dislocations unbound into a new phase of matter.

The discovery of the hexatic phase was cited in the award of the 1982 Oliver E. Buckley Condensed Matter Physics Prize to B.I. Halperin and in the MacArthur Prize Fellowship awarded to D.R. Nelson in 1984.

## The Hexatic Phase of Matter

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Most of us were taught that classical physics allows simple atoms and molecules to appear in just three distinct equilibrium forms: solid, liquid, and gas. In 1978, while pursuing a theory of melting of two-dimensional crystals, we discovered that a fourth "hexatic" phase of matter can be interposed between the liquid and the solid. This new phase of matter is hypothesized to play a role in a variety of two- and three-dimensional materials. Its existence has been demonstrated most convincingly in smectic liquid crystals<sup>1</sup> and in a model colloid system consisting of a single layer of polystyrene spheres immersed in water.<sup>2</sup> Hexatic order was recently discovered in flux line arrays in the new high-temperature superconductors.<sup>3</sup>

In the late 1970s, we became interested in defect-mediated phase transitions,

1. Pindak R, Moncton D E, Davey S C & Goodby J W. X-ray observation of a slacked hexatic liquid-crystal B phase.

*Phys. Rev. Lett.* 46:1135. 1981. (Cited 135 times.)

2. Murray C A & van Winkle D H. Experimental observation of two-stage melting in a classical two-dimensional screened coulomb system. *Phys. Rev. Lett.* 58:1200. 1987.

3. Murray C A, Gammel P L, Bishop D J, Mitei D B & Kapitulnik A. Observation of a hexatic vortex glass in flux lattice of the high-superconductor  $\text{Bi}_{21}\text{Sr}_{19}\text{Ca}_{99}\text{Cu}_2\text{O}_{8+8}$ . *Phys. Rev. Lett.* 64:2312. 1990.

4. Kosterlitz J M & Thouless D J. Ordering, metastability and phase transitions in two-dimensional systems. *J. Phys.—C—Solid State Phys.* 6:1181-203. 1973. (Cited 2,000 times.) [See also: Thouless D. Defect-driven phase transitions. Citation Classic. *Current Contents/Physical, Chemical & Earth Sciences* 31(44):8. 4 November 1991.]

5. Halperin B I & Nelson D R. Theory of two dimensional melting.

*Phys. Rev. Lett.* 41:121-4. 1978:41:519. 1978. (Cited 415 times.)

6. Young A P. Melting and the vector coulomb gas in two dimensions.

*Phys. Rev. B—Condensed Matter* 19:1855. 1979. (Cited 250 times.)

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