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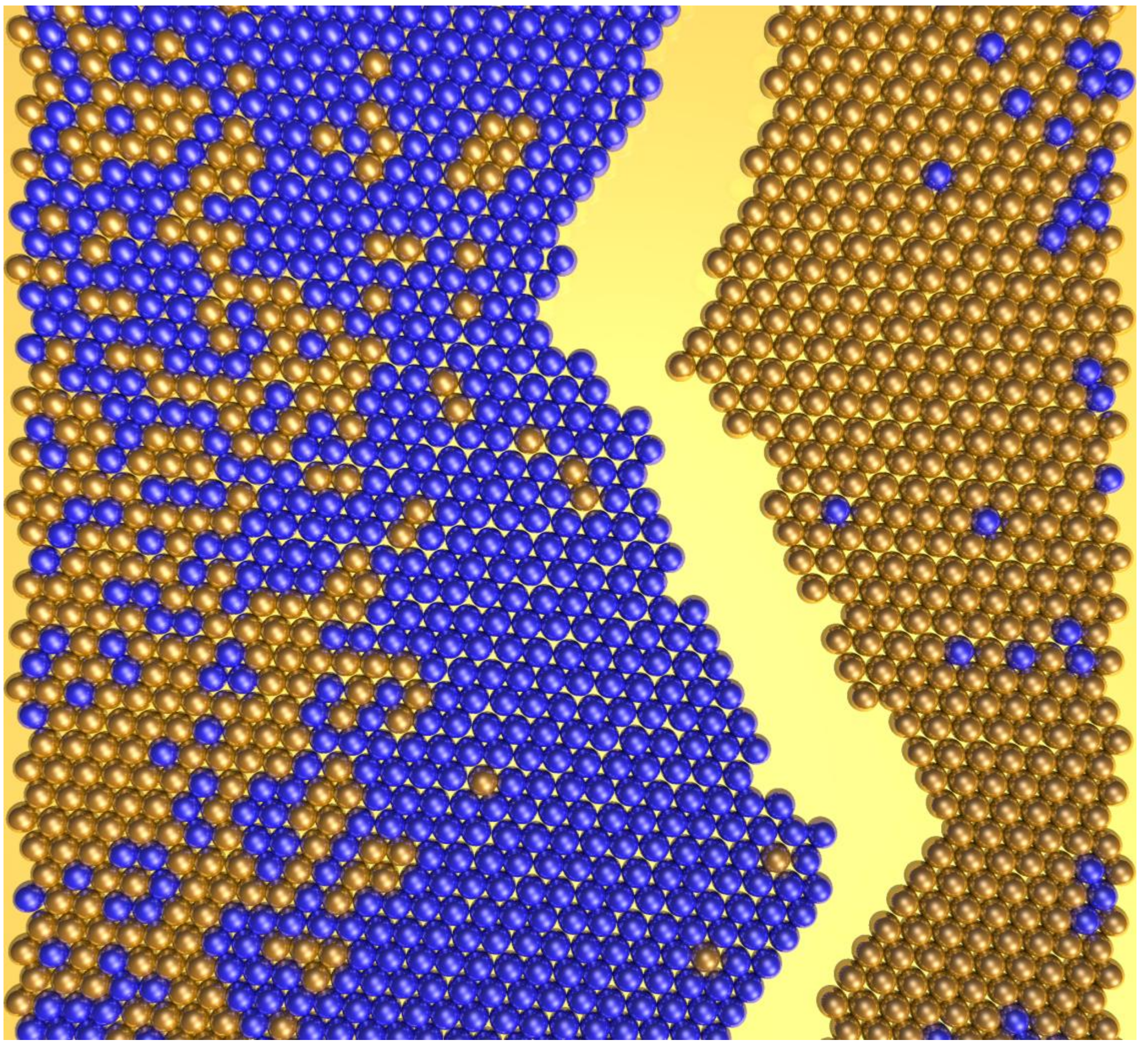
Colloids give insights into new dynamic forms of matter

Driven colloids show how transitions between different phases of nonequilibrium states can occur.

Image courtesy of Soft Matter (cover page).



Colloids under external driving form a clogged or jammed state similar to that found in traffic jams and other systems that form dynamic states of matter when driven. The image shows a jammed state in which rightward moving colloidal particles (blue) block the motion of leftward moving colloidal particles (gold) and vice versa.

The Science

One of the great triumphs of physical science is the development of equilibrium thermodynamics and statistical mechanics that permits the classification of different states of matter such as solid, liquid, and gas, as well as the transitions between them. What is not known is whether there are analogous states of matter under nonequilibrium conditions, and whether transitions between such nonequilibrium states could occur. It would be extremely valuable to find relatively simple model systems that clearly exhibit distinct phases of driven matter as well as dynamic phase transitions. A group in the Theoretical Division at Los Alamos has identified just such a system in the form of two species of non-thermal disks driven in opposite directions. Despite the apparent simplicity of this system, it exhibits four distinct nonequilibrium phases of driven matter along with two different types of transitions among these phases.

The Impact

The driven disk system provides a simple model that unambiguously exhibits several different nonequilibrium phase transitions. It can be used as the basis for understanding more complex driven systems with longer range interactions, hydrodynamic effects, or different types of driving. Examples of such systems include sheared solids, structural transformations produced by shocks, traffic flow, earthquakes, and driven quantum systems.

Summary

Equilibrium thermodynamics and statistical mechanics provide an underlying foundation for understanding different equilibrium states of matter and the phase transitions that separate them. One of the grand challenge problems in the physical sciences is to develop a similar framework for nonequilibrium systems to address problems such as the changes of materials under a load, transitions from flowing to jammed traffic, the self-organization of biological and social systems, or laminar to turbulent flow transitions. Due to the high level of complexity in such systems, it is very difficult to identify distinct phases or even to determine proper methods for quantifying the behavior. The granular disk model produced in the Theoretical Division, although apparently very simple, clearly exhibits distinct and easily-identifiable nonequilibrium phases of matter with well-defined unique spatial and dynamic structures. This model exhibits both first and second order dynamic phase transitions that resemble equilibrium transitions; however, instead of an equilibrium signature appearing in spatial structures, the transition can be detected using dynamic quantities which exhibit universal scaling behavior similar to that found in equilibrium transitions. Insights developed using this model can be applied to more complex nonequilibrium phenomena, where similar temporal scaling relations can arise.

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Publications

C. Reichhardt and C.J.O. Reichhardt, Velocity force curves, laning, and jamming for oppositely driven disk systems. *Soft Matter* **14**, 490–498 (2018). *Cover Page*

C. Reichhardt and C.J.O. Reichhardt, Depinning and nonequilibrium dynamic phases of particle assemblies driven over random and ordered substrates: a review. *Rep. Prog. Phys.* **80**, 026501 (2017).

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