Phase Diagram of Janus Particles
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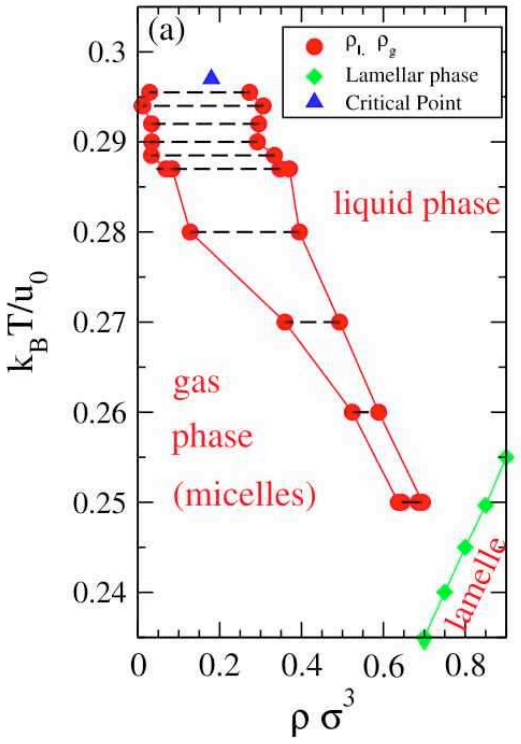
Recommended and a commentary by Randall D. Kamien, University of Pennsylvania

Diblock copolymers, the longer cousins of the amphiphilic building blocks of the cell, not only have a robust and varied phase diagram, but they are now the basis for templating, lithography, and a variety of bosonic bandgap materials [1]. As interest has turned to smaller scales, the complex fluids world has responded by developing Janus particles [2], nanometer-scale colloids that, like the moon and the force, have a "dark" side and a "light" side which are chemically different and repel. These spherical amphiphiles can be manipulated using the highly developed techniques of colloid science and now the balance of repulsion and entropy can be mixed with the exquisite control [3] of depletion and surface templating. Unlike typical Lennard-Jones or hard-sphere fluids, which have solid and fluid phases, the phase diagram of Janus particles can include regions in which the particles aggregate into micelles which subsequently order.



Phase diagram in the reduced temperature – reduced pressure plane.
From the paper.

The authors have performed extensive simulations and found precisely this phenomenon. Below the usual liquid-gas critical point, the coexistence region actually *shrinks* as a result of the formation of micelles in the gas phase. In fact, the numerical phase diagram

(reproduced here) suggests that the two phases rejoin. Even stranger is the fact that the measured energy of the gas phase is lower than that of the liquid phase, meaning that the gas phase is lower entropy than the liquid. This is reminiscent of the the liquid-solid transition in water (below 5000 Atmospheres!) where the ice phase is less dense than the liquid. Analogously, the gaseous phase is more ordered. The authors demonstrate that this is a Heisenberg-like order in which the arrows which point from dark to light on the Janus particles are more aligned than in the liquid state.

What is this good for? Imagine that the Janus particles contained magnetic or electric dipoles – could the surface interactions of the spheres be used to help align their contained moments? If so, it might be possible to create a "super paramagnetic" response, particularly if this gas-state ordering can be enhanced. This work now suggests many different avenues to explore, for instance anisotropic Janus particles where depletion, liquid-crystallinity, and surface interactions can all be exploited and controlled.

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[1] M. Muthukumar, C.K. Ober, and E.L. Thomas, Science **277** (1997) 1225 –1232.

[2] S. Granick, S. Jiang, and Q. Chen, Physics Today **62**:7 (2009) 68 – 69.

[3] A.D. Dinsmore, A.G. Yodh, and D.J. Pine, Nature **383** (1996) 239 – 242.