

The strange world of short-range potentials

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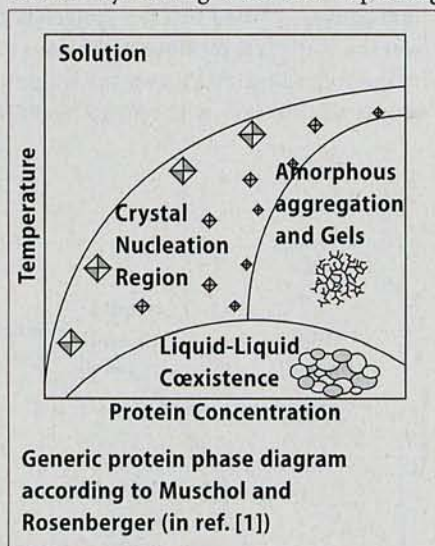
hot topic Protein Crystallization

The English poet Rupert Brooke wrote: "And sure, the reverent eye must see a purpose in Liquidity". Since we all owe our existence to the occurrence of the liquid state, we must agree with this sentence. But is this little pocket we call liquid an unavoidable feature of the phase diagram? Or can a thermodynamic system display just two stable phases, namely a solid and a single fluid phase? Apparently this is possible, provided that the range of the attractive part of the interaction potential is much shorter than the particle hard core diameter.

For such a potential, the critical point "sinks" within the fluid-crystal coexistence region, and the gas-liquid transition becomes metastable with respect to crystallization. This model can hardly find a physical realization in simple fluids, where the range of the potential is always comparable to the molecular size, but is verified experimentally in colloidal dispersions. Light scattering measurements show that both the phase diagram and the osmotic compressibility of a protein solution prone to crystallisation conform to those expected for very short-range attractive potentials.

Indeed, a phase separation into two fluid-like phases is often seen to come ahead of crystallisation for protein solutions

brought into the crystal nucleation region, while above the metastable critical point large fluctuations of concentration can considerably speed up the crystal growth kinetics. Moreover, for strong supersaturation, protein crystallization is often hindered by the formation of long-live metastable amorphous aggregates, another typical signature of very short-range potentials (see figure). However, the microscopic origin of such a short range potential is still unclear. Proteins are often crystallized by adding salts and exploiting



what is called the "salting-out" effect. But the amount of salt needed to trigger crystal nucleation greatly exceeds what is required for simply screening the electrostatic interactions due to protein surface charges. Moreover, the salting-out effect is strongly salt-specific. A well-defined scale of efficiency for different electrolytes in precipitating proteins was established more than a century ago. This scale, known as the "Hofmeister series", also controls many other thermodynamic properties of aqueous electrolyte solutions, like the surface tension or the critical micellar concentration of solubilized surfactants. Neutron scattering measurements by Leberman and Soper suggest that salts induce strong changes in the solvent structure like those induced by a pressure jump, but so far no microscopic quantitative model is available for these effects. Since obtaining protein crystals is a fundamental step in order to derive protein structure and to elucidate their biochemical role, further progress along these lines could shed additional light on that beautiful condensed matter system we call life.

The authors are working at Pavia and Milan

Further reading

A collection of recent papers relating to protein phase behaviour and crystallization can be found in *Journal of Crystal Growth* 196 (1998) • Protein crystallization methods are discussed in *Crystallisation of Nucleic Acids and Proteins: A Practical Approach* edited by A. Ducruix and R. Giegè (Oxford University Press, Oxford, 1992) • For a review of the Hofmeister series see K. D. Collins and M. W. Washabaugh *Quarterly Review of Biophysics* 18 323 (1985)

Counting the molecules

Pedro Tarazona, Spain

hot topic Theories of Freezing

It seems easy to distinguish fluids from solids, but their microscopic similarity is the main difficulty in the study of freezing. Theoretically, liquids are characterized by their density and short-ranged correlation structure. However, these aspects do not show a clear contrast in relation to crystals. The qualitative difference comes from the long-ranged molecular order, which produces rigidity and other macroscopic characteristics of crystals—but it is difficult to include its effects in the relative thermodynamic stability of fluids and solids. Hard spheres are the simplest representation of freezing and

exposes its subtleties: the model is purely entropic (allowed configurations have no potential energy) so that it freezes when the entropy in the "ordered" crystal becomes larger than in the "disordered" fluid, contrary to the usual view of entropy as a measure of "disorder". How do we calculate this entropy?

The answer comes from the density functional techniques developed for inhomogeneous fluids in external potentials. Crystalline order implies that the effects of boundaries extend over the whole system, while in fluids they disappear over microscopic distances. Thus, crystals may be de-

scribed as self-maintained inhomogeneous fluids, with density distributions consisting of narrow peaks arranged in regular lattices, fixed by distant boundaries. The development of density functional approximations for hard spheres during the 1980s, was rewarded with accurate predictions for their freezing, but only within a variational use of the formalism, with the crystal density distribution restricted to normalized peaks, describing the positions of each molecule. However, the full minimization of the free energy gave much poorer results, with wrong unit cell occupation. The approximations were good enough to calculate the entropy of inhomogeneous density distributions, but not to see the molecular discreteness.

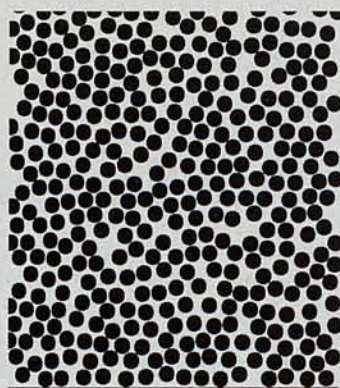
This problem has been solved by recent advances within fundamental measure theory, a geometrical approach based directly on the molecular shape, rather than on the usual excluded volume (which for

hard spheres is also a sphere with a radius twice as large). The earlier versions of this approach could not be used in the study of freezing because of strong divergences of geometrical origin, which have been removed using the "zero-dimension" limit of the equation of state: the free energy of small cavities which can only contain one hard sphere. These are the first theories of freezing in which the crystal is described as the global minimum of the free energy with respect to the density distribution, giving the correct occupation of the unit cell; they allow the study of problems for which the restricted variational approach was not valid.

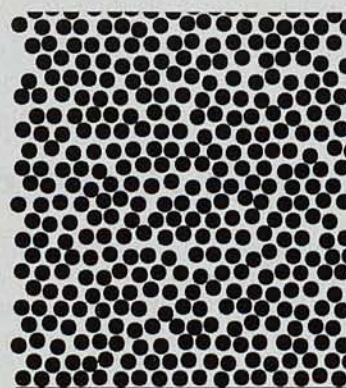
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Further reading

Fundamentals of Inhomogeneous Fluids by R. Evans (editor D. Henderson, Dekker, New York, 1992) • M. Baus *Journal of Physics of Condensed Matter* 2 2241 (1990) • Y. Rosenfeld, M. Schmidt, H. Löwen and P. Tarazona *Journal of Physics of Condensed Matter* 8 L577 (1997) • P. Tarazona, Y. Rosenfeld *Physical Review E* 55 R4873 (1997)



Fluid



Solid

Sketch of hard molecules in fluid and solid phases. The mean density and the local structure around each molecule are similar—but viewing the figure with small angle over the paper (try it) shows that the molecules in the solid keep the overall alignment along the main crystalline directions. Which phase has the larger entropy? The answer comes with the walls represented by the bottom lines: its effect in the fluid phase is limited to a few molecular layers and the density distribution averaged over the statistical configurations goes to a homogeneous bulk. In the solid the walls fix the crystalline lattice over the whole system and give a strongly inhomogeneous density distribution, with narrow peaks for the distribution of each molecule

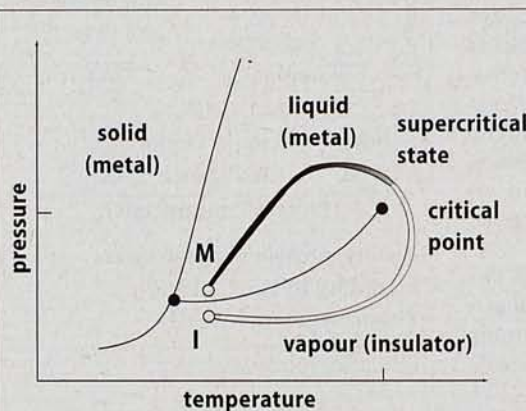
Metal or insulator?

Friedrich Hensel

hot topic Fluid Metals

Nearly four fifths of the elements in the periodic table are metals. These elements remain metallic when they are heated through their melting points at normal (1 bar) pressure. In contrast to melting, however, there are substantial changes in the electronic structure when the dense metallic liquid vaporizes. The liquid conducts electricity while the vapour does not. There is therefore a metal (M) insulator (I) transition that coincides exactly with the liquid-vapour transition, with the implication that both the density and the interparticle forces change.

However, this state of affairs applies only to conditions far below the critical point terminating the liquid-vapour phase line (see figure). Near the critical point, the liquid density is much less and the vapour density much greater. At what density does the vapour become a metallic fluid, or the liquid an insulator, along a line (see figure) going around the critical point starting from the ordinary liquid metal (point M) to the low density insu-



A typical metal in the pressure temperature plane. Below the critical point the liquid is in equilibrium with a low-density vapour phase. Above the critical temperature, where the liquid and vapour no longer coexist, the fluid is said to be in the supercritical state

lating vapour (point I)?

The problem that throughout the fluid range of metals the interparticle interaction must change from metallic to non-metallic binding has been a primary motivation for experiment. Most of this experimental effort has focused on mercury, caesium and rubidium because they have critical points that lie within current limits of static temperatures ($T_c < 2200$ K) and pressures ($p_c < 2000$ bar). Electrical, optical, magnetic, structural, thermodynamic and interfacial properties have been studied as functions of temperature and pressure up to and beyond the critical point. Each of these properties exhibits noteworthy variations with density. For example, the density dependence of the dynamic structure of liquid rubidium reveals that a monoatomic-molecular transition occurs in the metal-

non-metal transition region of the expanded liquid analogous to that suggested to occur in shock compressed hydrogen. This is a direct demonstration of the interplay between electronic structure and the atomic arrangement of the liquid. It supports the view that the transition to a metallic state in hydrogen and the alkali metals evolves from the diatomic system.

Another interesting feature is provided by the behaviour of mercury in the vicinity of a non-metallic substrate. Indeed, the most familiar example from everyday experience of a non-wetting substance is metallic liquid mercury on a non-metallic solid. However, when mercury in contact with sapphire is heated near to its liquid vapour critical point a first order wetting transition occurs at a wetting temperature T_w . This transition is accompanied