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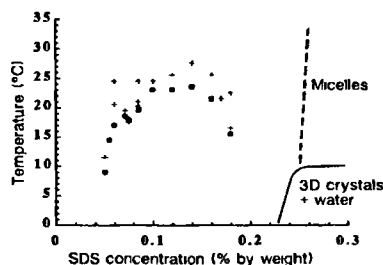


Figure 1. Phase diagram depicting different states of SDS monolayers as a function of concentration and temperature. The circles and the crosses (obtained by two different techniques) represent transition points from the higher-temperature liquid phase to the lower-temperature solid phase. [From Berge *et al.*, *Nature*, 1991, 350, 322]

Faceted two-dimensional crystals

K. A. Suresh

That a periodic stacking of spheres in three dimensions (3D) results in facets was shown long ago by Kepler¹. Naturally occurring crystals, in general, exhibit beautiful facets. This was the clue to the idea that the constituent atoms of the crystal must be arranged in a periodic fashion, later confirmed by X-ray studies. What about two-dimensional (2D) solids? Do they exhibit facets? This has been an important question for quite some time. 3D solids have 2D surfaces that are curved for amorphous solids and faceted for crystals. In 2D systems, the atoms or molecules are confined to a plane. Examples are the monomolecular films grown on solid or liquid surfaces. Their boundaries are one-dimensional. If regular crystals were to occur in 2D then facets should appear with the facet boundaries made up of straight lines.

Interestingly, Peierls² and Landau³ showed purely from thermodynamic considerations that at equilibrium and at non-zero temperatures 2D solids cannot have periodicity or long-range positional order. Therefore this theory rules out the possibility of the occurrence of 2D crystals. This leads to the absence of facets. But in a non equilibrium state, i.e. in a dynamical situation, faceted 2D crystals are not forbidden. In fact, computer simulations by Savit and Ziff⁴ have shown the possibility of 2D-crystal growth patterns with well-defined facets.

Recently Berge *et al.*⁵ reported the important observation of faceted crystals in 2D. Berge *et al.* dissolved sodium dodecyl sulphate (SDS) in water. In such a system, some of the SDS goes into the bulk while some

stays on the surface, forming a monolayer. This monolayer exhibits a liquid phase at higher temperatures and a solid phase at lower temperatures. To probe the state of aggregation in the monolayer, Berge *et al.* added minute quantities of the fluorescent dye 12-NBD-stearic acid to the system. These molecules being amphiphilic did not dissolve in the bulk but stayed on the surface. Further, they dissolved in the monolayer in the liquid phase and were expelled from the monolayer in the solid phase. This property was used to detect the liquid-solid phase transition of the monolayer. Under a fluorescence microscope the liquid monolayer containing the dye appeared bright while the solid monolayer without the dye appeared dark. Thus liquid-to-solid phase transition and growth of the solid phase was directly observed. The liquid-solid transition temperatures depended on the concentration of the SDS dissolved in water. These transitions existed only for low SDS concentrations. At high SDS concentrations micelles and 3D crystals were found in the bulk (see Figure 1). Around the SDS concentration of 0.055%, the liquid-to-solid phase transition resulted in the growth of faceted hexagonal crystallites of about 50 microns in size (Figure 2). However, during further growth, these facets became unstable and changed their shapes. One such instability, with zig-zag branches emanating from each corner, is shown in Figure 3. At any given temperature, if the monolayer was allowed to attain equilibrium, the facets smoothened out. At higher SDS concentrations the phase transition from the liquid to the solid phase resulted in domains of smooth bound-



Figure 2. Hexagonally faceted crystal growth observed on cooling the SDS monolayer to solid phase at SDS concentration of 0.055% by weight in water. [From Berge *et al.*, *Nature*, 1991, 350, 322]

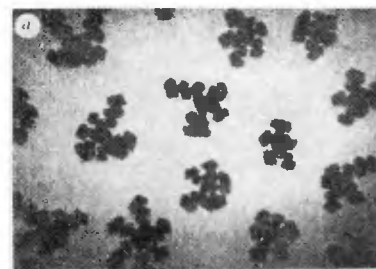


Figure 3. One type of instability observed during growth of faceted morphology in SDS monolayers. [From Berge *et al.*, *Nature*, 1991, 350, 322]

aries. These observations of faceted crystals in 2D show that during growth the constituent molecules can have long-range positional order although in thermodynamic equilibrium this is not stable.

Berge *et al.* point out important questions that their observations raise. For instance one does not yet know the mechanism of faceted growth in dynamical situations which also allows for a

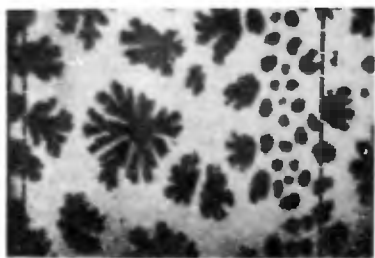


Figure 4. Liquid condensed growth patterns obtained on compressing a myristic-acid monolayer in the liquid expanded phase. The large pattern at the centre is about 200 microns in size. [From Suresh *et al.*, *Europhys. Lett.*, 1988, 6, 437]

continuous transition from faceted to smooth shapes. It is also not clear whether the earlier computer simula-

tions⁴ describe a realistic model of this system. It should be emphasized that these structures are not the only ones found in monolayers. There have been reports of a variety of patterns⁶⁻⁸ during 2D growth processes in monolayers. One such interesting case is the growth of liquid condensed domains (see Figure 4) obtained on compressing a myristic-acid monolayer in the liquid expanded phase. In the centre of Figure 4 there is a large self-similar pattern. Analysis shows that it has a fractal dimension of 1.8 ± 0.1 . These patterns have branches that grow by smooth tip-splitting, and are very different from those shown in Figure 3 where the patterns have branches that grow without tip-splitting and are made up of straight edges. Even in these cases the mechanisms involved are not very clear.

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Gene wars

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Like in animals, in plants also, resource investment in offspring by parents is asymmetrical; the mother plant invests more resources in the development of seeds (offspring), while the contribution by the pollen parent (the father) is negligible. From the perspective of Darwin's theory of natural selection, selection must be acting on the mother plant for prudence in allocating her limited resources among offspring¹. Indeed, it has recently been shown that plants invest an optimal level of resources in each offspring^{2,3}. However, the interest of the offspring is not similar to that of the mother as long as they are sired by more than one father^{4,5}; selection acts on each offspring favouring increase in the offspring's own fitness by demanding more than the mother is selected to give. Hence it has been argued that, just as in animals⁴, in plants also, there exists a severe conflict between mother and offspring over allocation of resources⁵⁻⁷.

In such a scenario it is easy to visualize that natural selection would favour strategies in the pollen parent that render its offspring able to demand

more resources from the mother; on the other hand, the mother would be selected with strategies that refrain her offspring from drawing more resources. On the basis of this argument, Haig and Westoby^{8,9} and Haig and Graham¹⁰ predicted that parents should manipulate their share of the genes in offspring in such a way as to meet their respective interests. In other words Haig and Westoby predicted that identical alleles at the same locus in offspring should behave differently depending on their parental source; particularly so with respect to the genes involved in garnering resources from the mother.

Haig and Westoby⁹ have offered support for their prediction by drawing evidences from the literature on the genetics of maize. In plants the endosperm (constituted of maternal and paternal genomes in 2:1 proportion) is the major tissue that draws resources from the mother and nourishes the developing embryo¹¹. Development and normal functioning of the endosperm is hence imperative for maturation of seed and the embryo. By a complex set of genetic experiments, Lin¹² had shown

that normal development of endosperm in maize requires certain factors and that these factors are regulated by four loci resident on the long arm of chromosome 10. He also obtained two major types of endosperm tissue with four doses of the long arm of chromosome 10. The first type had all the four doses contributed by the ovule and the second type had two from the ovule and two from the pollen grain. Normal endosperms were formed only in the second type; in the first type, though the tissue contained all the loci in as many doses as the second type, the endosperms were poorly developed. This implies that these endosperm-factor alleles are inactivated when they are passed on through ovules but remain active if passed on through pollen grains.

Such parent-sex-specific activation of genes (PASSAGE) has in fact been reported in a few animals¹⁰, and for other traits such as texture, pigment and morphology of kernels in maize^{13,14}. Though the significance of these genes in the context of resource-drawing ability is not clear, it is interesting that there are pleiotropic effects of hormones regulating pigment formation on protein storage in the endosperm of cereals^{15,16}.

The 'passage' model probably helps in resolving one important problem of parent-offspring conflict. Alexander¹⁷