Stratification induced by evaporation

Paints and inks are examples of colloidal dispersions, consisting of tiny particles suspended in a liquid. When they are laid in a film on solid ground, such as a drywall or a piece of paper, the liquid evaporates, and the particles are condensed to form a solid layer. This is how we paint the wall in beautiful colors and write on paper.

There are many interesting physics under such a common phenomenon in our everyday life. As the liquid evaporates, particles below the surface are forced to move with the descending interface, resulting in an accumulation of particles near the interface. At the same time, particles are jostling randomly, undergoing the so-called Brownian motion. This Brownian motion is faster for smaller particles, so they can quickly move away from the interface where the particle concentration is high. Larger particles, on the contrary, move slowly and accumulate at the interface. The result is a layering structure with more large particles on the top, which is wildly assumed for any evaporation rate. Therefore it came out as a surprise when a group of researchers in Surrey, UK found exactly the opposite phenomena: when the evaporation rate is high, small particles accumulate near the interface [1].

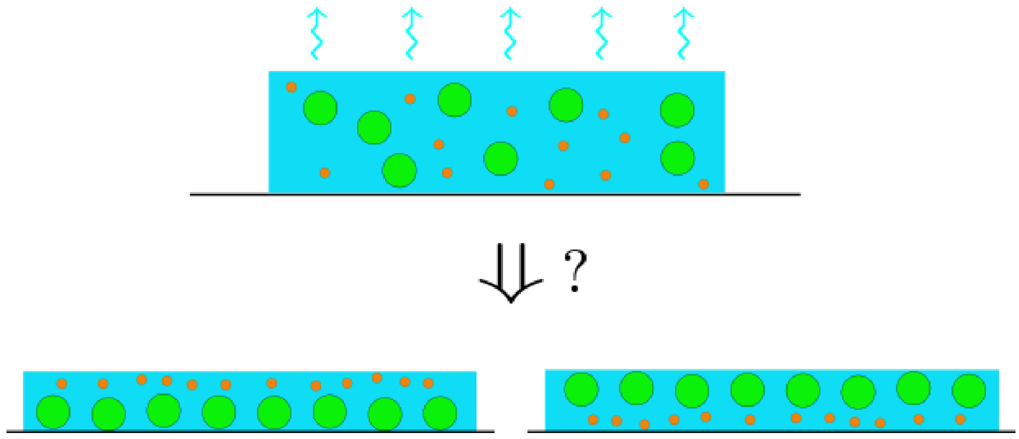

Fig. When a colloidal solution composed of binary mixture dries, the final structure depends on the evaporation rate.

To explain this effect, Jiajia Zhou and Ying Jiang from the School of Chemistry, together with Masao Doi, director of the Center of Soft Matter Physics and Its Applications, considered an evaporating film containing a binary mixture of small and big particles. They described each particle type using a standard diffusion equation, but different to previous theories, they explicitly accounted for an interaction between particles. This interaction, however, isn't symmetric: big particles find it difficult to squeeze into a packed region than small particles, much like an adult finds it harder to move on a crowded street than a child. This asymmetry pushes big particles away from the surface. Using numerical calculations, they identified a criterion for the small-on-top structure:

$$\alpha^2(1+\frac{v_{\rm ev}h_0}{D_1})\phi_{01} > 1$$

where α is the size ratio, v_{ev} is the evaporation rate, h_0 is the film thickness, D_1 and ϕ_{01} are the diffusion constant and the initial volume fraction for the small colloids, respectively. Therefore, there are two scenarios for the stratification: when the evaporation rate is low, the big colloids appear on the top; when the evaporation rate is high, the unusual small-on-top structure forms.

This research has been published in Physical Review Letters [2].

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References

[1] A. Fortini *et. al.*; Dynamic Stratification in Drying Films of Colloidal Mixtures， *Phys. Rev. Lett.*， 116， 118301 (2016).

[2] Jiajia Zhou， Ying Jiang， and Masao Doi; Cross Interaction Drives Stratification in Drying Film of Binary Colloidal Mixtures， *Phys. Rev. Lett.,* 118， 108002 (2017).