MATERIALS SCIENCE

Colloids get complex

Alfons van Blaaderen

Self-organization of soft-matter components can create complex and beautiful structures. But the intricate structures created by adding a second stage of organization could reveal more than just a pretty face.

The term 'soft matter' denotes materials that are easily deformed by external stresses, and encompasses liquid crystals, polymers, surfactants and colloids (particles dispersed within another medium). Their basic constituents have characteristic sizes of between several nanometres and several micrometres, and, crucially, have the potential to self-organize, forming beautiful, regular three-dimensional structures. A triplet of recent papers[1–3] presents the latest such structures: complex colloids formed through self-organization on scales up to a micrometre.

Alternative terms that have been used to describe these colloid structures — 'colloidal molecules', or 'patchy particles' — hardly do justice to their intricacy. What is considered a complex colloid is, admittedly, somewhat arbitrary: the colloidal 'ice-cream cones' (Fig. 1a) produced some years ago[4], which resulted from repeated polymerization and the subsequent phase separation of the polymers formed, would certainly have merited the term complex colloid. The innovation of recent efforts, however, is that structures are being designed with a second stage of self-organization in mind. Such an approach, in which colloidal particles are first formed at soft-matter scales, and then built up to far more intricate structures, should allow unprecedented control over the three-dimensional organization of materials, as well as the combination of different materials over several length scales.

The results of Cho *et al.*[1], published in the *Journal of the American Chemical Society*, exemplify the fruits of this technique. The authors created complex colloidal structures (Fig. 1b, c) by drying emulsion droplets containing 'bidisperse' charged colloids, consisting of components of two quite different sizes — one on the nanometre and one on the micrometre scale. Using the same or opposite charges on the two components, an amazing richness of structural motifs could be obtained. Equally impressive results have been published by Lin *et al.*[2] (Fig. 1d) in *Chemistry of Materials* and by Zoldesi and Imhof[3] (Fig. 1e) in *Advanced Materials*. Their structures were fabricated by depositing silica on liquid crystals formed by surfactants[2], and through the regular deformation by osmotic stresses of thin siloxane shells grown around emulsion droplets that are monodisperse (all the same shape and size)[3].

It is important to mention at this point that

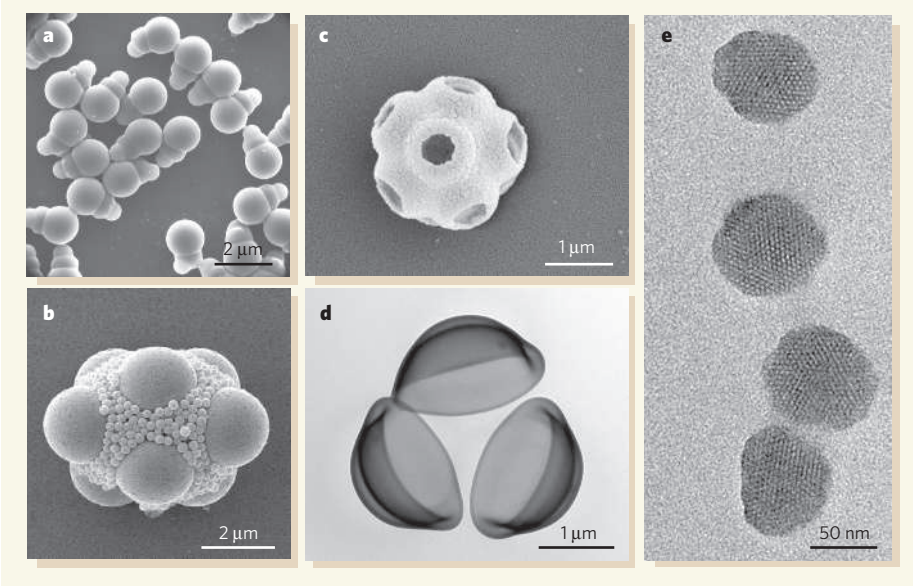

Figure 1 | A selection of complex colloids achieved by various means of self-organization. **a**, 'Ice-cream cones' resulting from repeated polymerization and phase separation between polymers of different composition[4]. **b**, **c**, Through controlled drying of a binary dispersion in water-in-oil emulsion droplets[1]; **b**, both colloids same charge; **c**, colloids with opposite charge. **d**, Through silica deposition on liquid crystal phases formed by surfactants[2]. **e**, Through osmotic stress deformation of thin hybrid siloxane shells after growing them on monodisperse oil droplets[3]. (Courtesy of: **a**, John Wiley, Inc.; **b**, **c**, American Chemical Society; **d**, C. M. van Kats, D. C. 't Hart and J. D. Meeldijk; **e**, C. I. Zoldesi and A. Imhof. All scale bars are approximate.)

50 YEARS AGO

"The training of university teachers" — The question of the advisability and possibility of providing new recruits to university teaching with some initial guidance in the technique of their calling has been examined by S. Radcliffe, lecturer in German at the University of Bristol... In general, lecturers are conscientious about the matter of their lectures, but give little thought to their form or their delivery... [Radcliffe] suggests that an artist requires some basic instruction, at least in the rudiments of his craft. The following are a few of the purely mechanical skills which might be considered desirable in a good teacher or lecturer. First, the adoption of a fitting speed and clarity of diction. Secondly, the clear formulation and appropriate stressing of the main points of the subject under review. Thirdly, the ability to use a blackboard successfully. Fourthly, the 'staging' of material to make it come 'alive'... Learning the students' names is an essential requirement in establishing closer contact with them...The prompt return of written work not only helps to keep up students' interest in their subject, but also gives the right to demand written work from the students within the time-limit specified.

From *Nature* 4 February 1956.

100 YEARS AGO

"The Revolution of the Corpuscle"

A corpuscle once did oscillate so
quickly to and fro,
He always raised disturbances
wherever he did go.
He struggled hard for freedom
against a powerful foe —
An atom — who would not let
him go.
The aether trembled at his
agitations
In a manner so familiar that I only
need to say,
In accordance with Clerk
Maxwell's six equations
It tickled people's optics far away.
You can feel the way it's done,
You may trace them as they run
— $d\gamma$ by dy less $d\beta$ by dz is equal
$K.dX/dt$

From *Nature* 1 February 1906.

50 & 100 YEARS AGO

complex shape is no prerequisite for complex interaction. The adsorption of charged molecules on colloids with sizes of the order of micrometres[5] and several nanometres[6] has been shown, for example, to result in charges small enough that ionic colloidal crystals — crystals comprising particles of opposite charge — can form. The added complexity of the interactions between oppositely charged spheres, compared with components with the same charge, has already resulted in the number of different types of binary colloidal crystal that have been fabricated doubling within a few months[5,6].

Starting self-assembly with complex colloids, however, offers increased possibilities. This is nicely demonstrated by a modest goal that many groups are aiming for: the creation of colloidal crystals with diamond symmetry. Such structures could be used to create a photonic crystal with a robust 'band gap' that can inhibit the propagation of light and modify the spontaneous emission of photons at visible wavelengths. These crystals are potentially as useful for manipulating the flow of light waves as semiconductor crystals have become for manipulating the flow of electrons. The interest in these three-dimensional structures is so great that they have even been assembled do-it-yourself style by placing thousands of colloids into a diamond lattice one by one[7]. But, whereas just a few years ago most considered the creation of diamond lattices by self-assembly to be wishful thinking, several approaches now seem to make it an immediate prospect. Some proposed schemes, based on theory and computer simulations, make use of complex spherical colloids with either tetrahedrally arranged attractive patches[8] or, remarkably, non-additive spherically symmetric potentials that might be produced using particles coated with complementary strands of DNA (that is, that can bind together to form double-stranded DNA)[9].

For a second self-organization step to succeed in any system, all particles must be monodisperse and the yield of the first step must be high. The polydisperse emulsion droplets created by Cho *et al.*[1] are therefore at present unsuited for self-organization into more complex three-dimensional structures, because no two colloid particles that they produce are exactly the same. But the path to monodispersity, clearly outlined by the authors, should not be too arduous.

Going even further than this, a crystalline arrangement of smaller monodisperse nanoparticles between larger spheres, or a mixture of oppositely charged and monodisperse nanocrystals of different composition, could be created. Transistors with a conventional two-dimensional layout can be made from self-organized colloidal crystals of nanoparticles[10]: by self-organizing such semiconducting colloidal crystals between larger colloids, such as those devised by Cho *et al.*, individual transistors could be arranged into regular, three-dimensional structures. A three-dimensional wiring system could also conceivably be established by using spheres that comprise a conducting and an insulating part as the larger building blocks, allowing each transistor to be addressed individually as it sits in the lattice.

Even though the complex colloidal structures now being created are beginning to show a faint resemblance to the beautiful silica structures produced by diatoms, natural examples of self-organization on multiple length scales and from different materials are generally still far ahead of any human design. Such structures are always available in case we run out of inspiration[11]. ■

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1. Cho, Y. S. *et al. J. Am. Chem. Soc.* **127,** 15968–15975 (2005).
2. Lin, Y. S. *et al. Chem. Mater.* **17,** 4570–4573 (2005).
3. Zoldesi, C. I. & Imhof, A. *Adv. Mater.* **17,** 924–928 (2005).
4. Sheu, H. R., El-Aasser, M. S. & Vanderhoff, J. W. *J. Polym. Sci. A* **28,** 629–651 (1990).
5. Leunissen, M. E. *et al. Nature* **438,** 235–239 (2005).
6. Shevchenko, E. V., Talapin, D. V., Kotov, N. A., O'Brien, S. & Murray, C. B. *Nature* **439,** 55–59 (2006).
7. Garcia-Santamaría, F. *et al. Adv. Mater.* **14,** 1144–1147 (2002).
8. Zhang, Z., Keys, A. S., Chen, T. & Glotzer, S. C. *Langmuir* **21,** 11547–11551 (2005).
9. Tkachenko, A. V. *Phys. Rev. Lett.* **89,** 148303 (2002).
10. Talapin, D. V. & Murray, C. B. *Science* **310,** 86–89 (2005).
11. Mann, S. *Biomineralization: Principles and Concepts in Bioinorganic Materials Chemistry* (Oxford Univ. Press, 2001).

NEUROBIOLOGY

Memories of a fruitfly

William G. Quinn

Despite its tiny size, the fruitfly brain is staggeringly intricate. So teasing apart how it remembers things — even a simple line pattern — is a daunting task. Progress is being made, thanks to genetic innovations.

Neuroscientists these days have a satisfactory understanding of how individual neurons work and of how they communicate with their immediate neighbours. By contrast, understanding at the next level of organization is hazier; for example, how neurons form functional circuits, how these circuits encode behaviour and particularly how experience changes the activity and connectivity in circuits to alter behaviour.

In this fog, a natural question is: how simple a system can one study profitably? Molluscs such as the marine snail *Aplysia* have yielded much insight because they have large, simple neuronal circuits. However, these animals perform only very basic behaviours. Insects, on the other hand, often have intricate neural circuits and complex stereotyped behaviours, such as the dance language of the honeybee. But their neurons have seemed too small and tangled for conventional analyses. Advances in genetic techniques have overcome this problem of scale, and in this issue Liu *et al.* (page 551)[1] use these ingenious methods to begin to dissect finely how the fruitfly *Drosophila* learns visual patterns.

The authors take advantage of 'jumping genes', which can hop about the fly genome and splice themselves into chromosomes at random points. A jumping gene can be tailored to carry along another gene of interest — a transgene. If the transgene (called 'TG-1', say) is jumped into the DNA near a naturally occurring gene, it is usually expressed in the same tissues as the natural gene[2]. This jumping-gene method is now highly developed in *Drosophila*, so that large numbers of fly

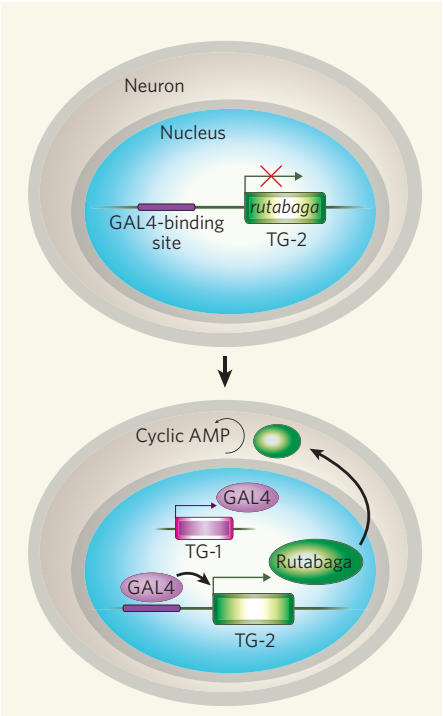

Figure 1 | Expressing a learning enzyme in selected cells. Liu *et al.*[1] used a strain of fruitfly that lacks a functional *rutabaga* gene, and added a substitute *rutabaga* gene (TG-2) that could be controlled by the transcriptional activator GAL4. By breeding these flies with various strains that express GAL4 only in certain subsets of neurons (from TG-1), they could ensure that the Rutabaga protein was produced only in those neurons. They then tested the flies' memories of various visual patterns.