FLOCCULATION

Colloids stick to fractal rules

John Rarity

A TWO-DIMENSIONAL projection of a tree's root system looks remarkably like an overhead view of a river delta. Both are random fractals and the similarities arise from similar large-scale rules of growth which seem not to be influenced by their detailed constituents. The attraction of fractal theories of nature is that the application of such large-scale geometrical rules can lead to simple universal properties in many complex, random-growth processes. One such process that has been popular with the colloid scientist since the days of the Faraday gold sol is the phenomenon of colloidal aggregation. In their letter elsewhere in this issue (*Nature* **339**, 360–362; 1989), M.Y. Lin *et al.* present electron micrographs of aggregates of colloidal gold, polystyrene and silica: the obvious similarities between these provide compelling visual evidence for universalities in their reactions.

Colloids, being suspensions of small particles in a fluid, are thermodynamically unstable to aggregation and survive only because of strong repulsive forces between the particles. Aggregation is thus inevitable when repulsive barriers are reduced, by various means specific to the constituents of the colloid. Two rate-limiting processes control the growth of random aggregates from the suspension. The first is the time taken for clusters to diffuse into contact with each other to allow sticking to occur; the second is the probability of sticking on contact.

The large-scale rule which leads to fractal properties of the aggregates is simply the geometrical limitation on close diffusive approach of two irregularly shaped objects. If particles stick on first contact and the bonds are stiff, one expects quite tenuous structures to evolve. If there is a low sticking probability per contact, the aggregates will have time to explore the contact surface and can interpenetrate somewhat before sticking, leading to less tenuous structures. The fractal nature of the resulting structure arises because each successful collision leads to a drop in the mean density of the aggregate and, on average, we can relate the mass contained in the aggregate M to a measure of its radius R by a power law, $M \propto R^d$, where d is the fractal dimension, which can range from 3 for space filling objects (or aggregates whose density does not drop with mass) to 1 in the case of extremely tenuous (rod like) structures.

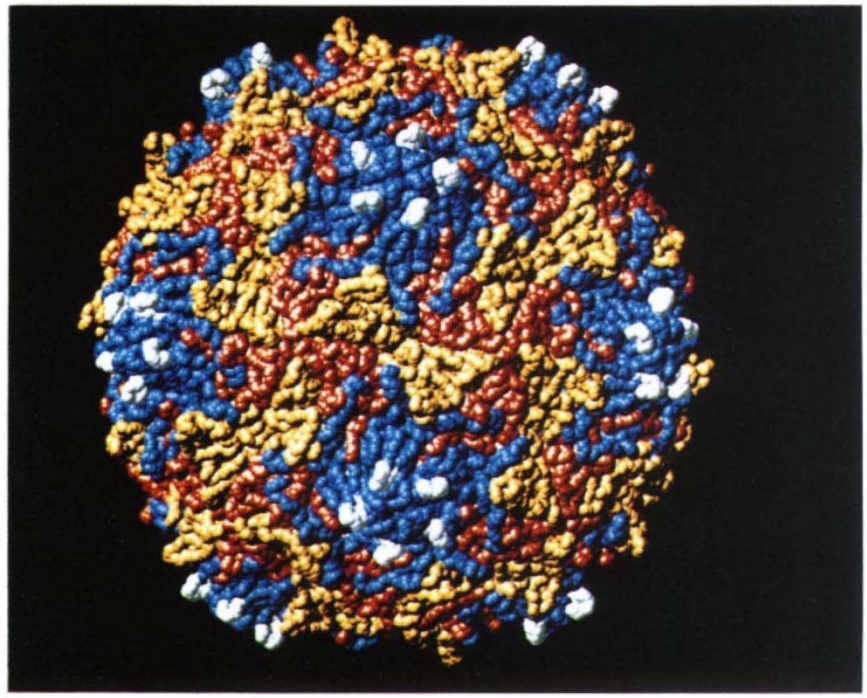
The two limiting regimes investigated by Lin *et al.* are described as diffusion-limited cluster aggregation (DLCA), in which aggregates stick on contact, and slow reaction-limited aggregation (RLCA) in which the sticking probability on contact is extremely low. Following the simplistic argument above, one expects DLCA aggregates to be more tenuous than RLCA aggregates. This is clearly the case for electron micrographs presented by Lin *et al.* on page 360. The fractal dimensions of the aggregates can be estimated by eye by noting that as these are two-dimensional projections, objects with fractal dimension smaller than 2 appear semi-transparent (as do DLCA aggregates) whereas objects with fractal dimension greater than 2 appear solid (RLCA aggregates).

Lin *et al.* measure the fractal dimension of large aggregates in suspension using static (elastic) light scattering. The inverse of the scattering vector q, the difference between the input and scattered wavevectors, defines a length scale (for coherent scattering) and the light scattered from an aggregate depends on the amount of mass typically found within a box of these dimensions. As a result the scattered intensity $I(q)$ falls with increasing scattering angle following the power law form $I(q) \propto q^{-d}$. All three aggregated systems show fractal dimensions $d \approx 2.1$ for RLCA and $d \approx 1.85$ for DLCA as suggested by the micrographs.

There is also good reason to believe that the kinetics of the aggregation reaction is also universal. The present workers follow the kinetics using dynamic light-scattering measurements to estimate a mean aggregate radius $\bar{R}$ and show data which illustrate that $\bar{R} \propto t^{1/d}$ (implying linear growth of aggregate mean mass) for DCLA and exponential growth, $\bar{R} \propto e^t$, for RCLA with all three systems studied. These data support the predictions of recent theory and simulations based on the simple rules of diffusion time and sticking probability governing the kinetics.

Is that it? Is the aggregation reaction now well understood? The neatly wrapped results presented here contrast sharply with those of new work by J.P. Wilcoxon *et al.* (*Phys. Rev.* **A39**, 2675–2688; 1989), who have been studying the aggregation of colloidal gold. Their article also reprints several earlier results from Lin *et al.* which at times disgree with those of the present work. Two main points of disagreement with the postulated universal kinetics are reported. First, Wilcoxon *et al.* point out that the strong optical resonance in aggregated gold at 680 nm can lead to measured fractal dimensions being wavelength dependent and report measurements of fractal dimensions ranging from 1.6 to 2 apparently uncorrelated with the aggregation kinetics. Second, they report a power-law growth of aggregate radius in DLCA with $\bar{R} \propto t^{0.4}$ when from the above we expect an exponent of

HIV/Poliovirus chimaera in AIDS research



THE outer surface of poliovirus, highlighting (in white) that part of the capsid protein, VP1, which has been replaced by part of the envelope glycoprotein of human immunodeficiency virus-1 in the chimaeric virus whose immunological properties are described by Evans *et al.* on page 385. The bulk of VP1 is shown in blue, whereas VP2 and VP3 are in yellow and red, respectively. (The figure was kindly prepared by C. Lockshin, D. J. Filman and J. M. Hogle of the Research Institute of Scripps Clinic.) □

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