example, Mirkin and colleagues prepared CsCl lattices from quantum dots of two different sizes as well as from combinations of any two types of PAE of similar size irrespective of composition[3]. In each case, the inorganic core played no role in determining the resulting structure, which was instead dictated by the hybridization of the DNA linkers.

Mirkin and co-authors' work opens up new perspectives for structure formation of nanoparticle-based solids as well as for technologically relevant applications in, for example, plasmonics, catalysis or intracellular delivery[11]. The ability to design nanoparticle superlattices by varying the interparticle distance, and number and type of nearest neighbours, should make it possible to synthesize novel nanomaterials with tailored structural and physical characteristics. Synergetic experimental and theoretical efforts may then lead to further understanding of collective phenomena in three-dimensionally coupled nanoparticles — such as the evolution of photonic band structures or the magnetic coupling between regularly dispersed magnetic centres in a highly ordered matrix — and ultimately lead to applications in optical or magnetic data processing and storage. It would also be expected that the guiding principles of Mirkin and colleagues' approach will stimulate the scientific community to create, understand and apply nanoparticle-based materials with programmed properties that can't be found in atom- or molecule-based solids. ❐

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References

1. Schmid, G. (ed.) *Nanoparticles – From Theory to Application* 2nd edn (Wiley, 2010).
2. Talapin, D. V., Lee, J.-S., Kovalenko, M. V. & Shevchenko, E. V. *Chem. Rev.* **110,** 389–458 (2010).
3. Zhang, C. *et al. Nature Mater.* **12,** 741–746 (2013).
4. Mirkin, C. A., Letsinger, R. L., Mucic, R. C. & Storhoff, J. J. *Nature* **382,** 607–609 (1996).
5. Alivisatos, A. P. *et al. Nature* **382,** 609–611 (1996).
6. Park, S. *et al. Nature* **451,** 553–556 (2008).
7. Nykypanchuk, D., Maye, M. M., van der Lelie, D. & Gang, O. *Nature* **451,** 549–552 (2008).
8. Agard, N. J., Prescher, J. A. & Bertozzi, C. R. *J. Am. Chem. Soc.* **126,** 15046–15047 (2004).
9. Pauling, L. *The Nature of the Chemical Bond* 3rd edn (Cornell Univ. Press, 1960).
10. Macfarlane, R. J. *et al. Science* **334,** 204–208 (2011).
11. Cutler, J. I., Auyeung, E. & Mirkin, C. A. *J. Am. Chem. Soc.* **134,** 1376–1391 (2012).

MATERIAL WITNESS

COLLOIDS GET ACTIVE

PHILIP BALL

Natural philosophers have been seeing signs of 'life' in non-living matter ever since Aristotle. But that motley enterprise has always been handicapped by a lack of clarity about what qualifies as life-like. When in 1828 Robert Brown first saw pollen grains dancing in suspension, he imagined that this jiggling activity revealed the 'vital force' animating all matter. But the association of random motion with heat defeated any easy equivalence of motion and life. When 60 years later another botanist, Friedrich Reinitzer, discovered spontaneous molecular alignment in liquid crystals, Ernst Haeckel leapt to the conclusion that organization, not motion, is life's most fundamental feature. Erwin Schrödinger refined that idea by suggesting it is non-equilibrium organization — the ability, as he put it, to feed on 'negative entropy' — that characterizes the living state.

One of the attractions of the notion of 'active matter' — the constituents of which move of their own accord in a non-thermal fashion, using free energy in the environment to sustain a non-equilibrium state — is that it unites all of these ideas about life's defining characteristics, while showing that none of them are to be equated with life itself. All the same, this field unifies concepts from the biological and abiotic sciences, so that, for example, schooling fish can be regarded as a kind of self-propelled, macroscopic liquid crystal, and bacterial swarms — the prototypical form of active matter — can be analysed using the physical scientists' conceptual tools of statistical mechanics and hydrodynamics.

Thus active matter shows that research at the interface of the living and non-living can be productively pursued without having to bother with the arbitrary old question of where to draw the boundary. Equally valuable is the focusing of attention on the mesoscale, the traditional regime of colloid science, as a locus of new phenomena made possible by relative liberation from both gravity's enervating tug and heat's crazy battering. Active matter injects fresh energy into the materials engineer's old (by now) discipline of complex fluids.

A recent review[1] outlines the physics of colloid-sized objects that 'swim', ranging from flagella-driven bacteria to Janus bimetallic microparticles propelled by an electrocatalytic reaction on one face. (Even in that seemingly simple case the propulsion mechanism is subtle, probably a kind of electrophoresis created by proton flow in the surrounding fluid.) The range of non-equilibrium behaviour in such systems, both natural and artificial, is vast[2]. Giomi *et al.* have shown, for example, how filaments propelled by motor proteins, such as the actin–myosin system, can produce nematically ordered arrangements with pulsatile activity that pumps solvent[3]. A new theoretical study[4] of this sort of system reveals ever-evolving patterns, including rings, spirals and aster-like entities reminiscent of those formed by kinesin-driven microtubules in mitosis and seen in a pioneering early study of active matter[5].

When that latter work was published, it was so unusual that no one knew quite what to do with it. One might say the same today of all active matter, but this will change, and concurrently so will our view of matter itself. It's not so much that life is the means by which matter achieves coordination and coherence; rather, we'll find life, here as elsewhere, to be a particularization of something more general. ❐

References

1. Poon, W. C. K. Preprint at http://www.arxiv.org/abs/1306.4799 (2013).
2. Ramaswamy, S. *Annu. Rev. Condens. Matter Phys.* **1,** 323–345 (2010).
3. Giomi, L., Mahadevan, L., Chakraborty, B. & Hagan, M. F. *Phys. Rev. Lett.* **106,** 218101 (2011).
4. Yang, X., Marenduzzo, D. & Marchetti, M. C. Preprint at http://www.arxiv.org/abs/1306.4067 (2013).
5. Nédélec, F. J., Surrey, T., Maggs, A. C. & Leibler, S. *Nature* **389,** 305–308 (1997).