Help from above

What role do macroscopic ideas and concepts play in the development of nanoscience and technology?

The field of nanotechnology is built on the fact that the nanoscale world is different from the everyday world. As the length scales that characterize materials become shorter, surface-area effects become more important and quantum effects kick in, leading to profound changes in the properties of materials and devices. These changes can be both advantageous and disadvantageous. The ability of quantum particles to tunnel through barriers that would repel classical particles underpins the operation of scanning tunnelling microscopes, for example, but it can be a headache when designing certain kinds of nanoelectronic devices. The design of nanoscale structures and devices also regularly involves approaches that are unfamiliar or even impossible on the macroscale. Basic building blocks can, for instance, self-assemble into various complex forms.

Despite the discrepancies and differing constraints, macroscopic concepts frequently influence research in nanoscience and technology. This will often involve attempts to imitate everyday tasks or to miniaturize everyday objects. Letters, words and countless university crests have been written on the nanoscale, most famously when the letters 'IBM' were spelt out with 35 xenon atoms on a nickel surface using a scanning tunnelling microsope[1,2]. Alternatively, actions such as bipedal walking have been mimicked using DNA molecules that can 'walk' along tracks made of DNA[3]. These walkers have also recently been used in nanoscale assembly lines, picking up different types of cargo as they move along a track[4]. Moreover, nanoscale analogues of various macroscopic devices have been created[5], including rotors, motors, switches, turnstiles and elevators, as well as some slightly more esoteric miniatures such as wheelbarrows and guitars.

Design principles established on the macroscale can also be transferred to the nanoscale, and an example of this can be seen in recent work on tensegrity structures. Tensegrity is a construction principle in which mechanically stable assemblies are formed through a balance between tensional and compressive forces; in contrast, most man-made structures rely on continuous compression for stability. In tensegrity structures, the tension is continuously transmitted across all components of the structure, which allows engineers and architects to build robust structures with very high strength-to-weight ratios. In these structures, an increase in tension in one component will lead to increase in tension in all components, and this change is countered by an increase in compression in certain structural elements. A pioneer of tensegrity is the artist Kenneth Snelson, who created sculptures of isolated metal rods held together by networks of tensed cables, and is perhaps best known for the Needle Tower: an 18-metre-high construct made of aluminium and stainless steel that is housed at the Hirshhorn Museum and Sculpture Garden in Washington DC.

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Inspired by such ideas, William Shih and colleagues, writing on page 520 of this issue, describe forming nanoscale tensegrity structures from DNA[6]. In the assemblies, rigid bundles of DNA double helices are connected by segments of single-stranded DNA that act as tension-bearing cables. The structures can self-assemble against forces of up to 14 pN — twice the stall force of powerful molecular motors such as kinesin and myosin — and the forces generated can also be used to bend the DNA bundles. This is not the first time that tensegrity structures have played a role in scientific research. It has, for example, been recognized that the design principles apply throughout living systems, and Donald Ingber — a member of the team that has developed the DNA tensegrity nanostructures — has previously shown that cells can be considered tensegrity structures[7].

The term tensegrity — a contraction of 'tensional integrity' — was coined by the architect Richard Buckminster Fuller, although he is better known for lending his name to the fullerenes. When Harry Kroto, James Heath, Sean O'Brien, Robert Curl and Richard Smalley[8] discovered C_{60} — a spherical molecule made up of carbon atoms arranged in 12 pentagons and 20 hexagons — 25 years ago, they considered a number of names for it. Ballene, spherene, soccerene and carbosoccer were all suggested, but they decided to name it Buckminsterfullerene because of the similarities between its structure and the structure of the geodesic domes designed by the architect.

Although the geodesic domes of Buckminster Fuller may have helped Kroto and colleagues understand the structure of C_{60} (ref. 9), an association with a macroscopic approach can sometimes be simply an afterthought or serve only to provide a convenient name. The work of Shih and colleagues, for example, uses a technique known as DNA origami[6]. This involves folding a long single strand of DNA into a predetermined shape using a number of shorter 'stapling' strands, but the Japanese art of paper folding was perhaps of limited inspiration in its conception.

Clearly the role of macroscopic concepts and approaches is varied, and is only one of a range of influences that can go into a single piece of research. Macroscopic design principles are often combined with nanospecific ideas, such as the combination of tensegrity and self-assembly in the work of Shih and colleagues. But like the forces in a tensegrity structure, which simultaneously push and pull against each other for stability, a combination of extremes is frequently a source of strength. ❒

References

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