flexibility even after freeze-drying and can be actuated with large strain in the dry state. Using a simple household magnet, the aerogel can be bent to absorb a droplet of water (Fig. 1d); 60 mg of aerogel can hold about 1 g of water and squeezing releases more than 95% of the water. Because some applications may require different mechanical properties, the dehydration process could be improved or additives might be used in the future to create a range of materials to meet these needs.

Although the properties of nanomaterials are frequently superior to those of their bulk counterparts, translating these advantages to macroscopic scales remains a challenge. For instance, cobalt ferrites are among the nanoparticles with the highest known remanence, but they need to have a narrow size distribution and a perfect organization to maintain close-to-perfect qualities at the bulk-materials level. Although Nogués and co-workers were able to manipulate the functionality of their materials by changing the nature of the ferrite and the sizes of the crystallite, the magnetic properties remain weak compared with similar bulk polycrystalline materials. It is likely that the magnetic nanoparticles in the aerogel are loosely arranged in chains and not oriented in a similar direction. Optimizing the magnetic dipoles would require better alignment, spacing and orientation of the single-domain ferrite particles as exemplified by magnetotactic bacteria, which require about 10 magnetic nanoparticles (~40 nm in diameter) to be oriented by the Earth's magnetic field[7].

Superior magnetic properties would facilitate the actuation of the aerogel materials because the same effect can be achieved using smaller fields. This seems to be a very challenging task for such a system, but staying with cellulose–nanoparticle hybrid composites and starting with wood instead of bacterial cellulose could be an inspiring approach. In fact, the preferential orientation of cellulose fibrils in wood has been shown to direct the synthesis of (non-functionalized and non-magnetic) particles in a parallel alignment[8]. In this case, however, the space between two fibrils is extremely limited and could prevent the association of single-domain magnetic nanoparticles with the cellulose network.

It will be of interest in the future to build on the present method and improve the material properties. For example, functionalizing the magnetic particles with a fluorescent layer may be useful for detection and sensing. The number of applications for such multifunctional materials has simply become larger and will continue to grow rapidly in the near future. ❐

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New twist on nanoscale motors

Linearly polarized light that does not possess any angular momentum can be used to rotate a gold nanostructure that can, in turn, rotate a much larger silica microdisk.

Erez Hasman

Although nanosubmarines have only ever been seen in science fiction movies, researchers have studied the nanoscale machinery found in cells — notably molecular motors powered by adenosine triphosphate (ATP)[1] — in great detail. They have also built other nanoscale components, such as actuators[2], from nanomaterials such as carbon nanotubes. Now, writing in *Nature Nanotechnology*, Xiang Zhang and colleagues[3] at the University of California, Berkeley, describe nanoscale motors powered by light that are capable of rotating objects with volumes that are 4,000 times larger than the volume of the motor. The Berkeley device has several advantages over existing approaches: it does not need ATP as a power source; it does not require electrical wiring; the speed and direction of the rotation can be remotely controlled by the light beam; and the motors are made from a material (gold) that is biologically compatible. Such a motor could prove useful in fields as diverse as research into the mechanical properties of DNA and nanoelectromechanical systems.

It is clear from Maxwell's equations that light carries both linear and angular momentum, so any interaction between light and matter will inevitably involve an exchange of momentum. The linear momentum of a photon is given by the expression $p = h/\lambda$, where h is Planck's constant and λ is the wavelength. The angular momentum of an optical beam can have two components: an intrinsic component that is associated with the handedness of the circular polarization; and an extrinsic or orbital component that is associated with the spatial structure of the beam[4]. The ultimate source of the intrinsic component is the spin angular momentum of the individual photons in the beam: this spin has a value of $h/2\pi$ and points either parallel to the photon direction (for left-hand circular polarization) or antiparallel (for right-hand circular polarization).

The effect of the spin angular momentum of light on a solid object was first demonstrated in 1936 when Richard Beth showed that circularly polarized light striking a quartz plate induced a torque on the plate as a result of angular momentum being transferred from the light to the plate[5]. This experiment relied on quartz being birefringent: that is, the refractive index depended on the polarization of the incident light. The mechanical equivalence of the spin and orbital angular momentum of photons has been confirmed in many experiments since then[6,7].

The torque induced by a light beam results from the total angular momentum being conserved during the scattering or absorption processes. Optical manipulation has been routinely used for many years to rotate micro- and nanoscale objects by exploiting either the intrinsic or extrinsic angular momentum of light, but Zhang and co-workers have now shown that a light beam that does not possess any angular momentum can also be used to rotate particles.

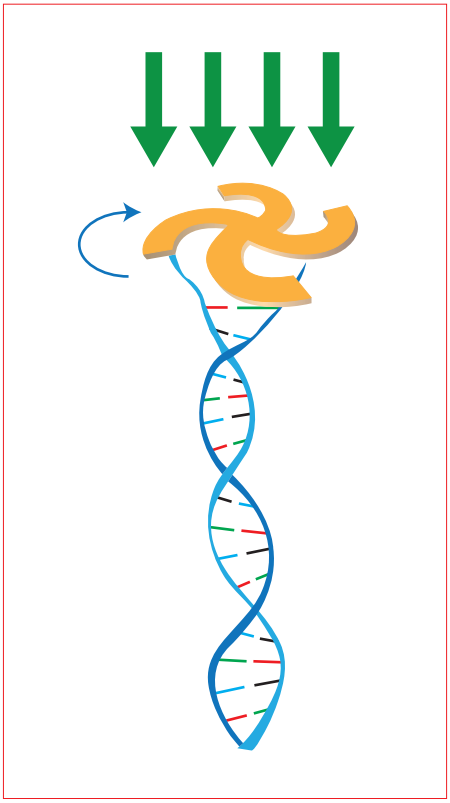

Figure 1 | When a beam of linearly polarized light (green arrows) without any angular momentum strikes a gammadion-shaped gold nanostructure, it is scattered by surface plasmons into a beam that does have angular momentum. The nanostructure therefore rotates in the opposite sense (blue arrow) to conserve angular momentum. Such a nanoscale motor could be used to, for example, unwind double-stranded DNA molecules.

In Beth's original experiment the incident beam, which was circularly polarized, was transformed into a linearly polarized beam as a result of each photon in the beam transferring $h/2\pi$ of angular momentum to the birefringent plate. The same basic physics (the conversion of one mode of polarization into another) was at work when Beth's experiment was repeated with birefringent microscopic particles[8]. In the early 1990s it was proposed[4] that a light beam could also exert a torque if the light–matter interaction reshaped the phase distribution of the light so that the scattered light beam had more or less orbital angular momentum than the incident light.

By taking this 'phase-front mode converter' approach the UC Berkeley team is able to use a light beam without any spin or orbital angular momentum to rotate a gammadion-shaped gold nanostructure (Fig. 1). The incident beam excites plasmons in the gold, which then re-emit light into a phase front with orbital angular momentum. By exploiting the properties of surface plasmons — localized excitations of the conduction electrons in the nanostructure — Zhang and co-workers[3] significantly enhance the light–matter interaction and obtain a rotational force that is strong enough to rotate a much larger silica microdisk. The surprising feature of the experiment is that the direction in which the motor rotates can be reversed by changing the wavelength of the light beam. (In separate work a group at Chalmers University used localized surface plasmons to rotate metallic nanowires[9], although the incident beam in these experiments did possess spin angular momentum.)

A related approach would be to use the orbital angular momentum of surface waves such as surface plasmon polaritons (travelling excitations that are produced when photons couple to surface plasmons) to rotate nanostructures. Researchers have been exploring the possibility of using a helical light beam to generate a plasmonic vortex — a helical mode with angular momentum that is confined to the surface of the nanostructure. It should also be possible to produce a plasmonic vortex by means of a spin–orbit interaction between the light beam and circular or spiral corrugations on the surface of the nanostructure[10]. Demonstrating nanoparticle rotation induced by a plasmonic vortex is an outstanding experimental challenge in this field. ❐

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