

BRIEF COMMUNICATIONS

Nanomotor rotates microscale objects

A molecular motor in a liquid-crystal film uses light to turn items thousands of times larger than itself.

Nanomachines of the future will require molecular-scale motors^{1–6} that can perform work and collectively induce controlled motion of much larger objects. We have designed a synthetic, light-driven molecular motor that is embedded in a liquid-crystal film and can rotate objects placed on the film that exceed the size of the motor molecule by a factor of 10,000. The changes in shape of the motor during the rotary steps cause a remarkable rotational reorganization of the liquid-crystal film and its surface relief, which ultimately causes the rotation of submillimetre-sized particles on the film.

We used a specially designed motor (molecule **1** in Fig. 1a) featuring a right-handed helical structure and a single stereogenic centre in the (upper) rotor part that dictates the direction of rotation, a central carbon–carbon double bond that functions as an axle, and a (lower) stator part that resembles the liquid-crystal host⁷. Upon irradiation of motor molecule **1** with ultraviolet light of wavelength 365 nm, a photochemical isomerization around the central double bond occurs that results in inversion of the helicity (from right-handed to left-handed). A subsequent thermal step, again with helix inversion (left- to right-handed), occurs readily at 20 °C (with a reaction-time half-life of 9.9 min in toluene). Two photochemical steps, each followed by a thermal step, add up to a full 360° rotary cycle.

This motor is very effective at inducing helical organization in a liquid-crystal film. With its surface exposed to the air, a unidirectionally aligned cholesteric liquid-crystal film containing 1% by weight of molecule **1** as a dopant shows a polygonal fingerprint texture that is typical of cholesteric liquid crystals that have their helix axes parallel to the surface⁸ (Fig. 1b). When this sample is irradiated with light of wavelength 365 nm under an optical microscope, the polygonal texture reorganizes in a rotational (clockwise) fashion (for movie, see supplementary information). The rate of rotation gradually decreases until the process halts after about 10 min.

Removing the light source causes the rotation to resume, this time in the opposite direction. The textures always rotate clockwise during irradiation and anticlockwise during the thermal isomerization step. Exchanging molecule **1** for its enantiomer induces rotation in the opposite direction, confirming that the direction of rotation of the liquid-crystal tex-

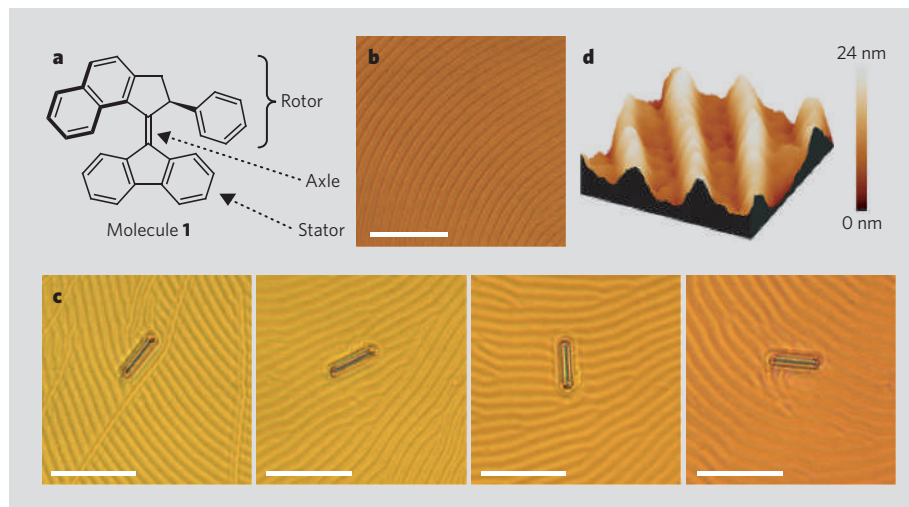


Figure 1 | Features of a light-driven molecular motor **a**, Structure of the motor (molecule **1**). Bonds in bold point out of the page. **b**, Polygonal texture of a liquid-crystal film doped with molecule **1** (1% by weight). **c**, Glass rod rotating on the liquid crystal during irradiation with ultraviolet light. Frames 1–4 (from left) were taken at 15-s intervals and show clockwise rotations of 28° (frame 2), 141° (frame 3) and 226° (frame 4) of the rod relative to the position in frame 1 (for movies, see supplementary information). Scale bars, 50 μm. **d**, Surface structure of the liquid-crystal film (atomic force microscopy image; 15 μm²).

ture is determined by the change in helicity of the motor.

The rotation of the texture induced by the motor can be harnessed to move submillimetre-sized particles placed on top of the film. Figure 1c shows the first stages (over 45 s) of a typical rotary motion of a microscopic glass rod (for movie, see supplementary information). The glass rod (5 × 28 μm) rotates in the same direction as the cholesteric texture during the photochemical and thermal steps of the motor at an average speed of 0.67 and 0.22 r.p.m., respectively.

Using non-contact atomic force microscopy, we found that the liquid-crystal film doped with molecule **1** has a surface relief that is 20 nm in height (Fig. 1d). Optical profilometry indicates that the orientation of this surface relief alters in response to photochemically or thermally induced topology changes in the embedded molecular motor (see methods in supplementary information). This reorganization generates a torque on the microscopic object that results in rotary motion.

We have described a collective change in helicity in a nanosized motor that can be used to rotate microscopic-scale objects by harvesting light energy, and have demonstrated that a rotary molecular motor can perform work.

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Supplementary Information accompanies this communication on Nature's website.

Competing financial interests: declared none.

Received 8 September 2005; accepted 1 February 2006. doi:10.1038/440163a