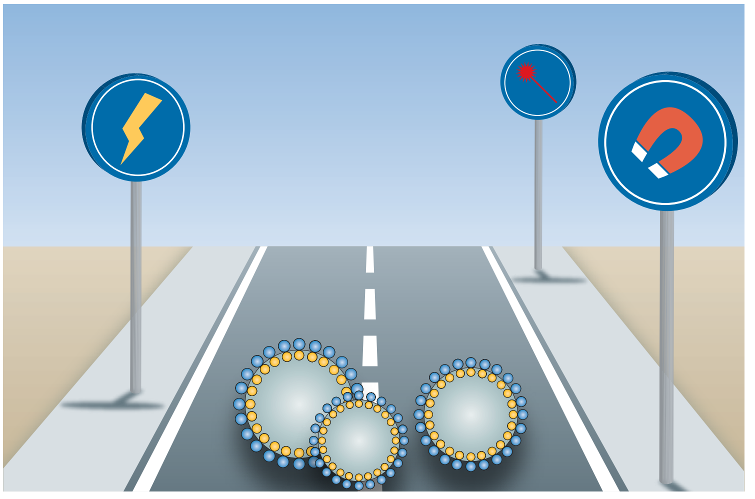
Nature Reviews Materials | Published online 31 Jan 2018; doi:10.1038/natrevmats.2018.6



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NANOPARTICLE SURFACTANTS

Active assemblies

Liquid droplets coated in surfactants can be moved, assembled and merged together in response to a range of stimuli. Combining these responses into one system is more challenging but promises to yield highly functional and active materials.

Now, writing in *Nature*, Bartosz Grzybowski and colleagues report surfactant-covered droplets that are simultaneously responsive to three different stimuli and exploit this versatility to manipulate the droplets. These stimuli can also be used to mix the content of the droplets, enabling their application as microreactors. "The key feature is the combination of nanoparticles with traditional surfactants, that is, polar/non-polar molecules, to give completely new types of behaviours," explains Grzybowski. "Depending on the composition of the nanoparticles, the surfactants are responsive to a range of different fields — magnetic, light and electrostatic stimuli," adds Grzybowski.

A dimeric arrangement consisting of gold nanoparticles and either magnetic iron oxide nanoparticles or non-magnetic lead sulphide nanoparticles forms the basis of the responsive system. The gold nanoparticles are functionalized with hydrophilic groups and the other nanoparticles are functionalized with hydrophobic groups. Thus, the dimers are amphiphilic in nature and form monolayers at aqueous/organic interfaces. The liquid droplets that are coated with these dimeric-nanoparticle surfactants are a 1:1 mixture of water and ethylene glycol.

Different stimuli impart fascinating behaviours to these surfactant-covered droplets. Light can be used to assemble droplets into hexagonal close-packed 2D arrangements on a timescale of about 10 to 20 seconds. Smaller droplets are able to make 3D structures. Light is also able to rotate the droplets owing to localized heating of the surfactants and the liquid within the droplet. The heated liquid convects in an upwards direction and hence the droplet always rotates away from the light source. As a consequence of the robustness of the nanoparticle-surfactant coating, this motion induces rotation of the surrounding droplets but in opposing directions to the powering droplet. This is analogous to mechanical gears and Grzybowski describes these torque-transmitting droplets as "soft gears that would deform but would not jam or break."

> The key feature is the combination of nanoparticles with traditional surfactants

Droplets coated with these multi-responsive surfactants can be used as microreactors. The researchers show how the droplets can be orientated by magnetic fields and then fused together by electrical fields to form channels between the droplets. Laser light can then be used to widen these channels and mix the contents of the droplets. "This ability to guide the microreactors using light, rather than pressure which is usually always needed in microfluidic systems, and to fuse droplets 'on-demand' enables the control of sequences of reactions in a fairly easy manner," says Grzybowski. "In addition, the rotation of droplets using light allows the mixing of content within the microreactor droplets — which is not as straightforward in microfluidic systems."

The responsive nature of this system promises opportunities for several applications including 'virtual microfluidics', which Grzybowski's team are currently pursuing.

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ORIGINAL ARTICLE Yang, Z. *et al.* Systems of mechanized and reactive droplets powered by multi-responsive surfactants. *Nature* **553**, 313–318 (2018)