chromo-capillarity : wavelength-dependent manipulation of a droplet by light

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Operations (driving, mixing, and handling) with small amounts of liquid usually rely on complex architectures that involve active (pumps and valves) and passive (channels) elements. Manipulation of liquid droplets by light is thus a promising yet challenging alternative. The most common strategy toward this goal uses solid surfaces with specific photosensitive surface properties.When a liquid droplet is deposited on such substrates, illumination by light induces a gradient of wettability resulting in simple and low-speed droplet motions (30 mm.s^{-1}).

Here we show that light can be used to create a wavelength-dependent interfacial tension gradient at a liquid/liquid interface, thus inducing interfacial and bulk flows able to generate droplet motion in the opposite direction to the gradient. This phenomenon, the chromocapillary effect, is obtained by illuminating an oil droplet that floats on a water bath containing a surfactant whose polarity depends on the illumination wavelength.

Firstly, the partial illumination of the droplet results in a reversible, wavelength-dependent motion of the droplet that can be repeated over several cycles. Then, a two-color concentric illumination allows one to build a "chromocapillary trap", which is used to manipulate the droplet along trajectories of any desired shapes, with a speed of 300 mm.s^{-1} and good precision.

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motivations : from synthesis of stimuli-responsive molecules to new applications

✓ responsive molecules for creating forces on a single object :

manipulation without contact at microscopic scale

for applications in biophysics

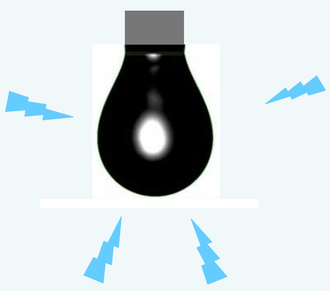
✓ developing stimuli-responsive materials :

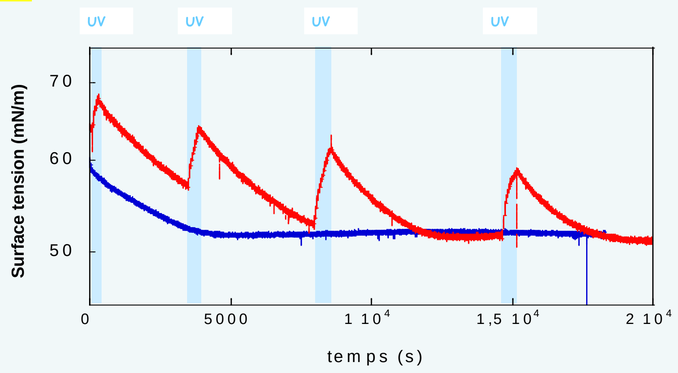
using soft dispersed systems (emulsions) as templates,

and doping their liquid-liquid interfaces

Interfacial studies : reaction to light stimuli ?

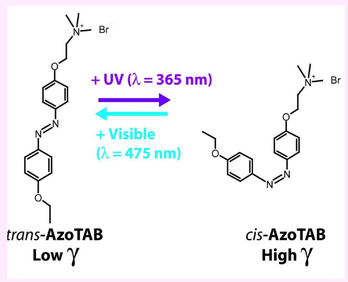
pendant drop at the tip of a syringe :
measuring surface tension vs time, with and without UV ?



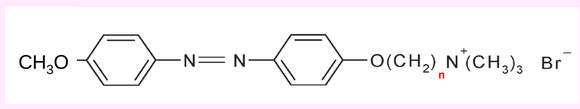


- Molecules act like a surfactant : adsorption, cmc, etc…
- Responsive interfaces : surface concentration depends significantly on illumination

Azotab-like molecules :

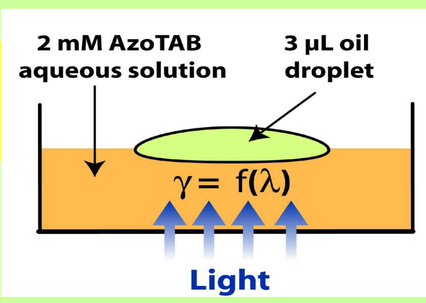


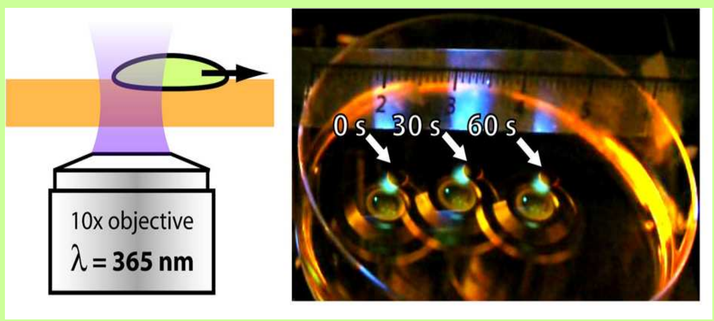
Home-made modified AzoTAB :



with n = 2,3,5,8

Experiments on a single floating droplet: inducing a motion ?





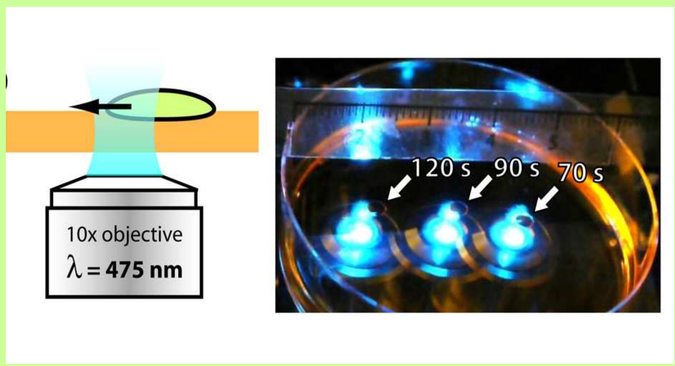
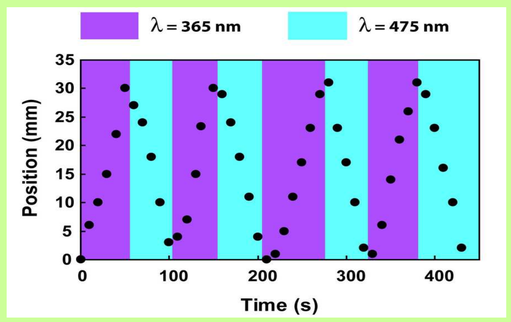
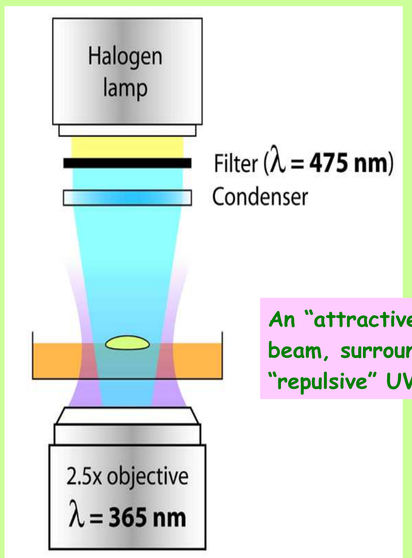


Photo-manipulation, which direction changes with the light wavelength !

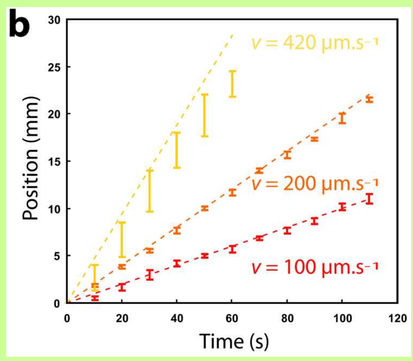


A capillary trap ?

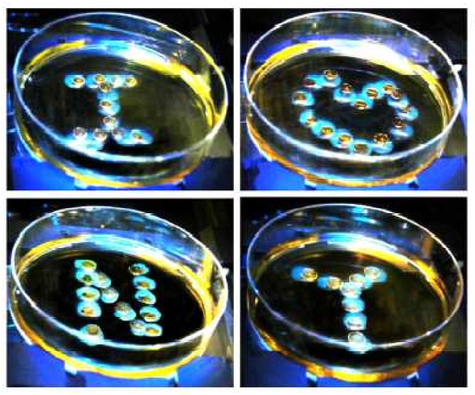


An "attractive" blue beam, surrounded by a "repulsive" UV beam

→ once in the middle of the beams, the droplet stay at rest



The drop can be moved along any complex path



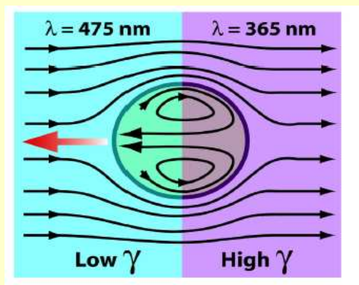
Superposition of pictures taken at different times

Which mechanisms at the origin of the motion ?

interfacial motion as a consequence of interfacial gradients

+

bulk flows coupled to the interfacial ones



for soft objects floating freely :

high γ → low γ

qualitatively analog to what is obtained with temperature gradient (thermo-capillarity)… but here the gradient is directly induced by light and its direction depends on the wavelength

inside re-circulation observed with tracers

- Light-induced droplet motion by wavelength-dependent liquid/liquid interfacial gradient : chromocapillary effect
- Light can be used as an external and (easily tunable!) stimulus for driving, mixing, handling small volumes of liquids
- Easy, fast and precise manipulation by a "chromocapillary trap"
- Open many perspectives for light-driven fluidics, safe handling of dangerous samples, reactive materials, etc…