Motion of optically heated spheres at the water-air interface

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A micrometre-sized spherical particle classically equilibrates at the water-air interface in partial wetting configuration, causing about no deformation to the interface. In condition of thermal equilibrium, the particle just undergoes faint Brownian motion, well visible under microscope. We report a few experimental observations when the particle is made of a light absorbing material and is heated up by a vertical laser beam (Fig.1). If the particle were transparent, made of e.g. glass or polystyrene (PS), forces due to light momentum transfer (radiation pressure) would simply bring it centered on the beam axis. In this case, the laser just acts as a 2d optical trap. The aim of this communication is to describe how this basic response is modified when laser induced heating of the particle's material comes into play. A striking observation, described below, is that *the particle behaves as a micro-swimmer* permanently orbiting around the laser beam axis, with *velocities on the order of several 100 µm/s* for a few milliwatts of laser power.

We use magnetic spheres ("magspheres"), about 5 µm in diameter. Such particles have a transparent PS spherical core, inside a PS shell filled with iron oxide crystallites. The magnetic properties of such particles are not exploited in our experiments. The interest of magspheres resides in the very strong absorption, together with high resistance to photo-degradation, of the iron oxide inclusions. Samples consist of very dilute suspensions of magspheres in water, inside a circular quartz cuvette with an open top (a kind of small Petri dish). A vertical laser beam (wavelength: 514 nm in air) is focused inside the sample by means of a long working distance objective. The beamwaistradius ω_0 can be varied from 1.3 to 20 µm. Some of the experiments are operated with a couple of contra-propagating beams [1]. The laser beam allows us to pick up a single particle in bulk suspension [1], and levitate it up to the W-A interface. In general, the particle locks to the interface in partial wetting configuration.

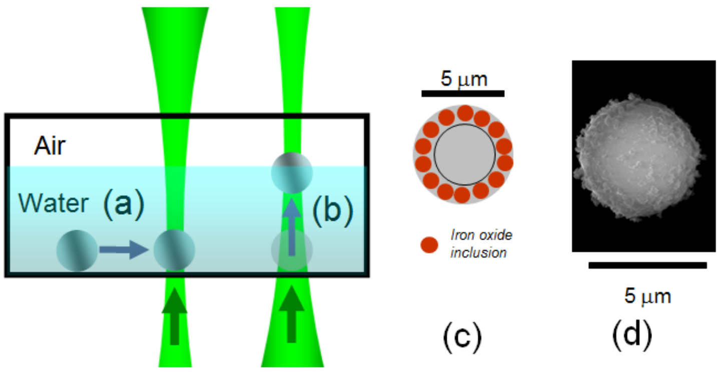

Figure 1: Optical capture (a) and levitation (b) of a particle up to W-A interface. Sketch for the internal structure of a magsphere (c) and electron microscope view of the particle surface (d).

Essential observations can be summarized as follows:

- At low laser power (e.g. P <<1 mW), the particle is captured on the laser beam axis, similarly to a transparent sphere.
- Above a threshold in power, the particle gets off-centered at a distance that depends on Pandω_0, and orbits at finite azimuthal velocityv_{orb}around the beam axis (Fig.2). The amplitude of v_{orb} depends on the particular experiment, meaning that apparently identical magspheres may show very different velocities under same operating conditions. v_{orb} may even reverse in sign in the course of a given experiment.
- The heating induced orbital rotation of the magsphere is absent if a layer of oil is added on top of the sample. It was only observed at the W-A interface.
- A few experiments have been carried out with a dilute suspension of sub-micrometer latex particles, used as tracers to reveal surface flows around a heated particle. At moderate power, these experiments reveal centripetal flows of the tracers, which tend to accumulate on the magspheres surface under laser illumination. The effect is reversible and repeatable in laser on- laser off sequences. At higher power, the surface flow self-organizes into vortices around the particle. Quadrupolar patterns [2] are well visible in certain experiments.

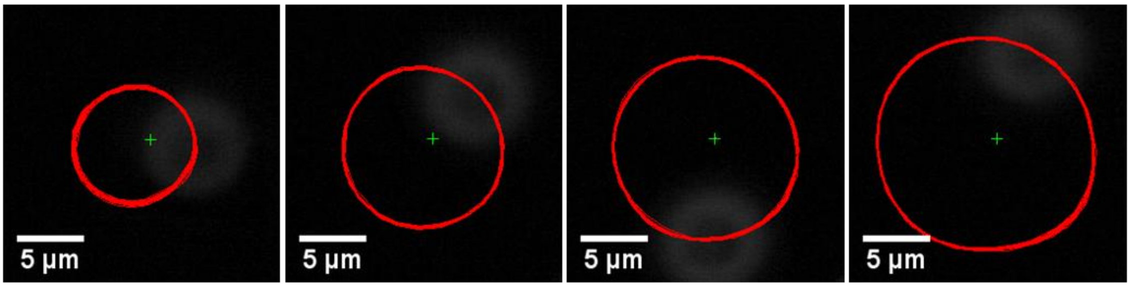

Figure 2: Particle's orbits around the laser beam axis (marked by a blue cross). ω_0 = 4.3 µm. The orbit radius increases with the laser power(3.2, 7.0, 10.1, 19.6 mW, from left to right).

We are currently speculating on the mechanisms at work in driving the particle's dynamic state. The above observations suggest that intense evaporation of water around the heated particle drives the flow close to the particle periphery. The influence of evaporation [3] is likely to be opposite to that of the Marangoni effect [4], which should act in moving the particle further off the laser axis. The fact that each particle stabilizes on a finite radius orbit might be the result of the balance between both antagonist effects.

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[1] F. Nadal, A. Dazzi, F. Argoul and B. Pouligny, Appl. Phys. Lett. **79**, 3887 (2001); B. Mihiretie, J.C. Loudet and B. Pouligny, J. Quant. Spectrosc.Radiat. Transfer **126**, 61 (2013)

[2] S. N. Varanakkottu, S. D. George, T. Baier, S. Hardt, M. Ewald and M. Biesalski, Angew. Chem. Int. Ed. **52**, 7291 (2013)

[3] H. Hu and R. Larson, J. Phys. Chem. B Lett. **110**, 7090 (2006)

[4] A. Würger, J. Fluid Mech. 752, 589 (2014)