# Bubbles with a Magnetic Coat

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A gas bubble in a liquid shrinks and grows in response to an oscillating pressure; yet it is very difficult to simultaneously gain control over its position in space. Our research group has found a simple recipe to "dress-up" gas bubbles with a shell of magnetic nanoparticles. Thereby, the bubble obtains a sufficiently high magnetic moment to overcome buoyancy; this can already be achieved with a simple household magnet. Yet, the bubble retains its ability to oscillate in a sound field. The one micrometer thick magnetic coating is formed by self assembly and the bubbles are between 50 micrometer and 1 millimeter large. These surprisingly stable magnetic bubbles are a novel tool to test fundamental fluid mechanic concepts and offer potential for remotely powered biomedical and microfluidic

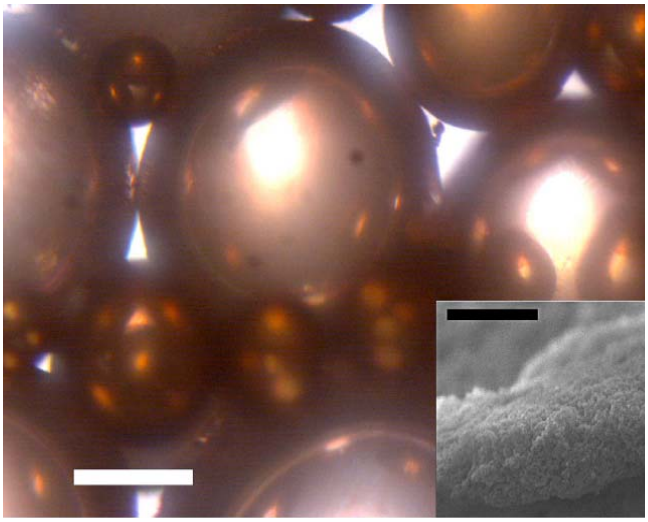

*Figure 1. Microscopic view of magnetic bubbles: The Christmas-tree-ball-like appearance of the magnetic bubbles is due to a thin layer of metallic nanoparticles (length of the scale bar 300 µm). The inset shows a cross section of the shell taken with a scanning electron microscope (length of the scale bar 1 µm).*

A collection of bubbles are depicted in figure 1; their metallic appearance is due to the adsorbed nanoparticles at the air water interface. Smaller sized bubbles have resonance frequencies in the 100kHz range whereas larger bubbles already oscillate at a few kilohertz. We have recorded the oscillation of a single bubble with high-speed camera at 200,000 frames/s. Also, we have found a way to measure the magnetic property of the bubble by balancing the magnetic field induced forces with the hydrodynamic forces.

Figure 2 below depicts a potential application with these new bubbles: They can be used as remotely controlled and powered actuators whereby the magnetic field positions the bubble, and the acoustic field delivers the energy to stir and mix the liquid.

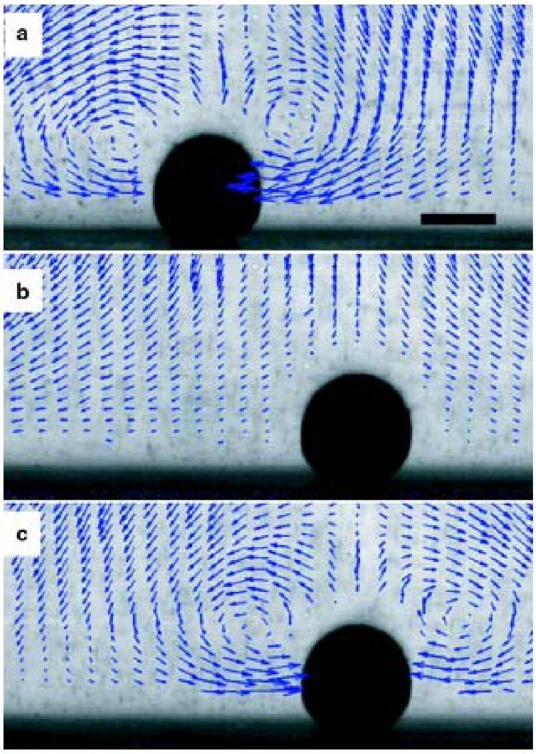


*Figure 2. (a) Magnetic bubble-induced microstreaming.*

*A single magnetic bubble is excited with an acoustic field which creates a streaming flow. The flow pattern is visualized with 3 µm diameter polystyrene particles At resonance a vortex ring is created at the bubble's upper pole. (b) The sound field is switched off, and the bubble is repositioned to the right using a permanent magnet. A residual stagnation type flow pattern remains. (c) The sound field (same amplitude and frequency) is switched on giving way to a very similar flow pattern translated to the right. The length of the scale bar is 100 µm*

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**Related Publication**:

Zhao, X., Quinto-Su, P. A., Ohl, C.D.
*Dynamics of magnetic bubbles in Acoustic and Magnetic Fields* Phys. Rev. Lett. 102 (2009)