Hydrodynamics of Super-Paramagnetic Micro Objects

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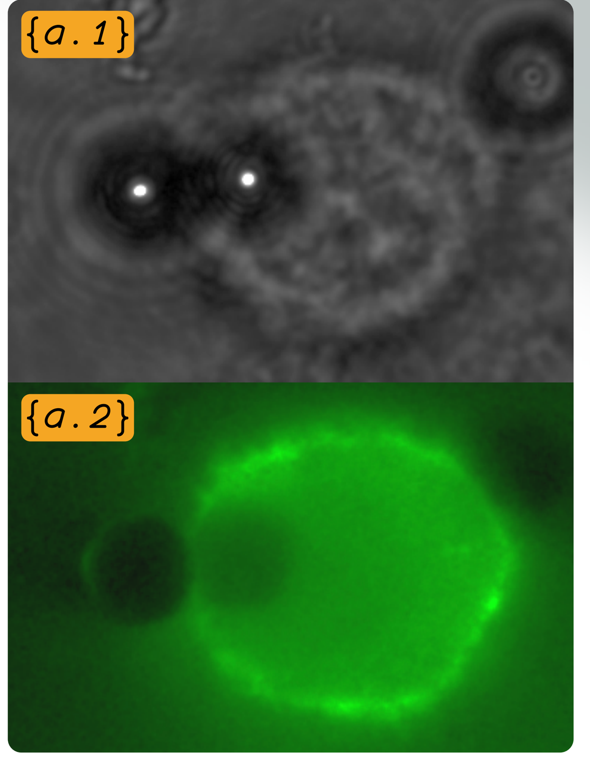
Super-paramagnetic micro-objects have found a host of applications in biological studies, including protein purification, measurements of mechanical properties of cellular cortex, and dynamic assembly of actin networks. Under a magnetic field, these objects self-assemble into complex chains where the forces are attractive and controllable by the field intensity. This promises to be an elegant tool for a broad range of applications in life and material science.

Depending upon the experimental requirements, the shape anisotropy of these objects are favourable.

Upon application of a homogenous magnetic field, the particles with anisotropic shapes align along their longest axis, providing the possibility to control their orientation and self assembly. In context of a particular study, different geometries and configuration of the particles may be favourable.

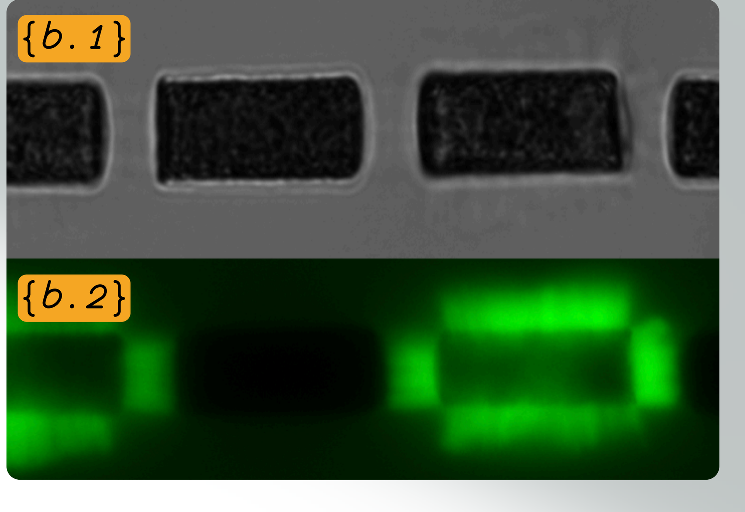
In this work, we present a method to study the Hydrodynamic drag between objects of different shapes under a magnetic field in a medium, and to provide a quantification for arbitrary configuration of shapes. Different configurations will be studied such as the ones shown in {1}.

Motivation



{a}

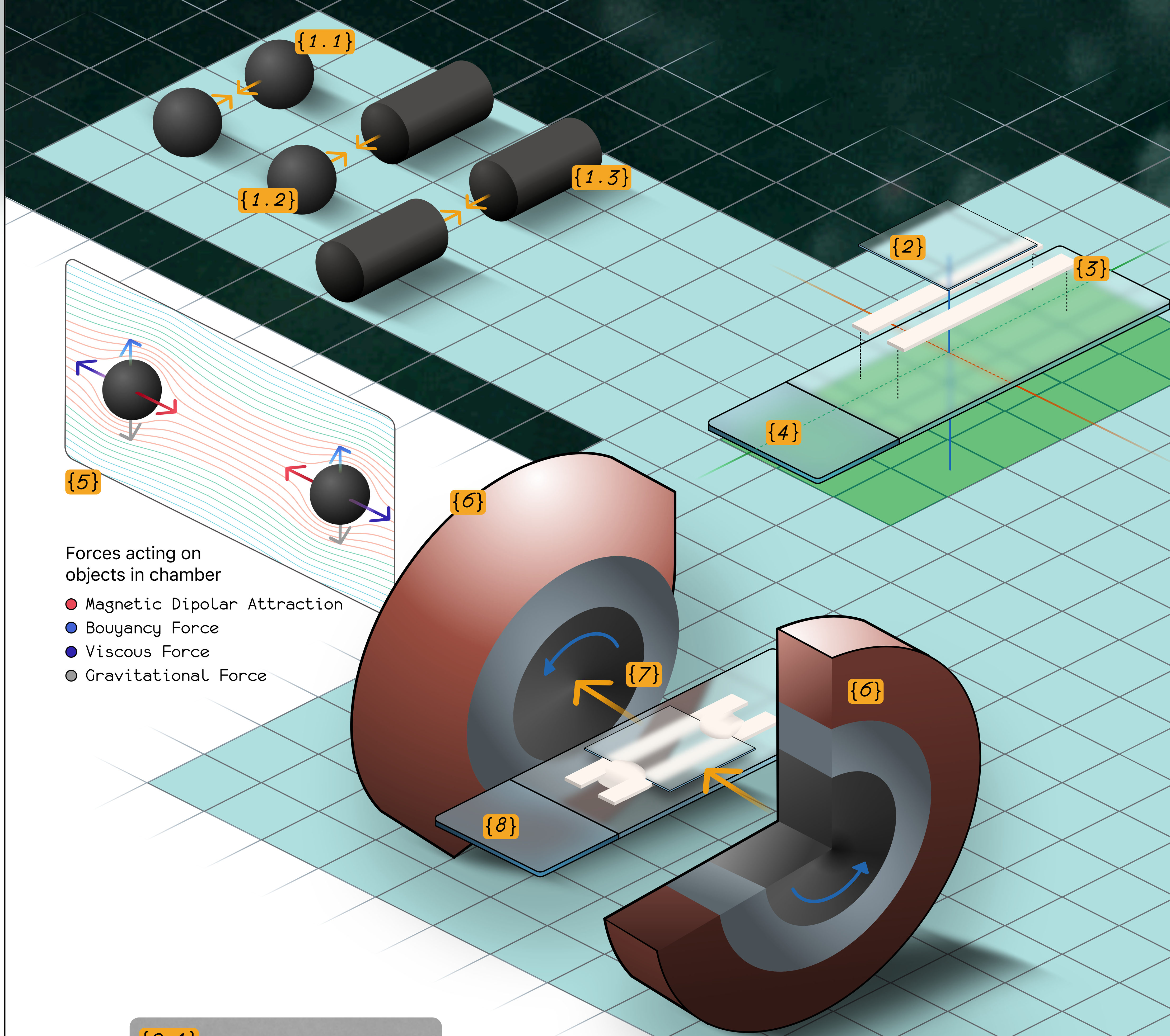
Biophysical properties of the cellular cortex can be studied by analysing the dipolar attraction of beads under regulated magnetic field.



{b}

Actin filaments are polymerized on the surface of microscopic magnetic cylinders {b.1}.

Modulation of external magnetic field allows us to manipulate the cylinders. This gives us a nanometer-resolution measurement of non-linear mechanical properties, and dynamic assembly of actin networks {b.2}.



Method

1. Super-Paramagnetic ***Dynabeads*® *450*** (r=2.2μm) are used. Sample is prepared with 0.5μl beads suspended in 100μl medium.
2. Sample **Chamber** {4} is prepared on a slide. To minimize surface friction, a coating of *BSA* is applied. The sample is then pipetted in, and the openings closed using wax {8}.
3. A pair of **coaxial-coil** {6} is used to generate a homogeneous magnetic field {7}. Gradient can be produced by activating only one coil. The intensity of the field is controlled via a constant-current power source.
4. Using high-speed camera, we capture the timelapse of beads motion at high frame rate. This timelapse is then analysed to locate and track the beads and provide the motion profile.

Analysis

There are several forces that act on the beads in the chamber, as shown in {5}. By restricting our analysis to the objects sufficiently far from the bottom of the chamber, we can avoid friction due to no-slip boundary condition.

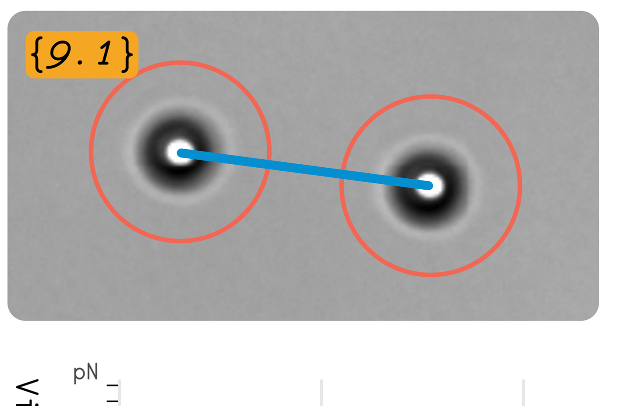
The viscous force in water medium is proportional to the speed of the beads, while the dipolar attraction depends on distance between them.

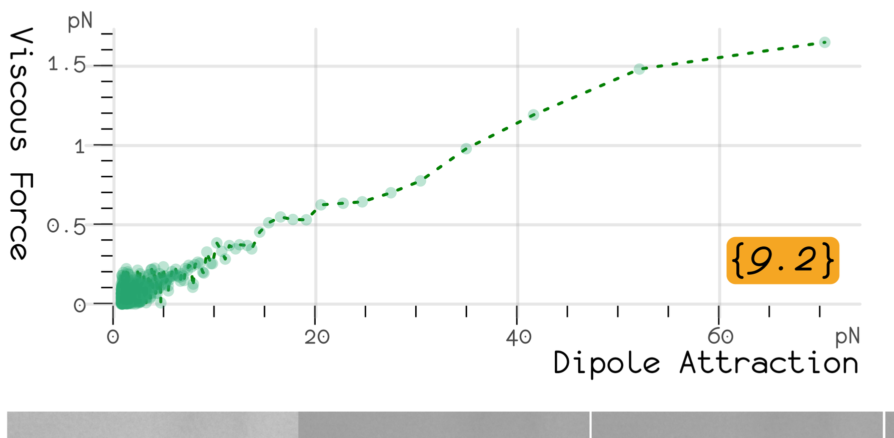
From the trajectory of the particles, we can calculate the *Viscous Force* acting on the beads {9}.

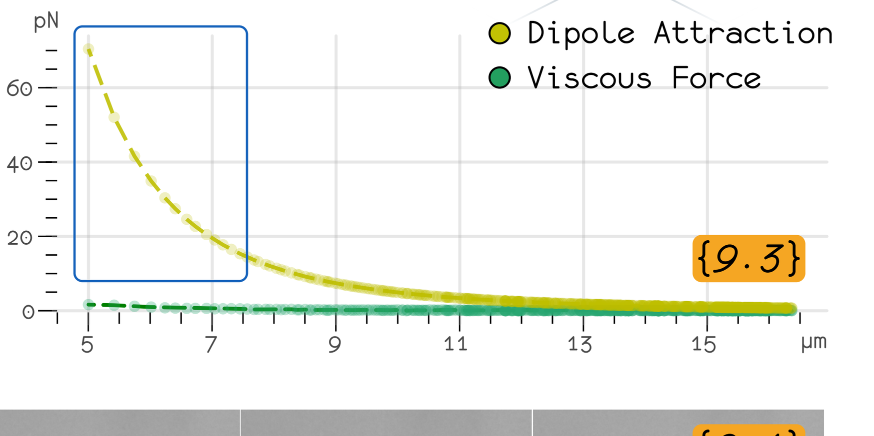
$$F_{dip} = \frac{3\mu_0}{2\pi}\frac{m^2}{d^4}$$

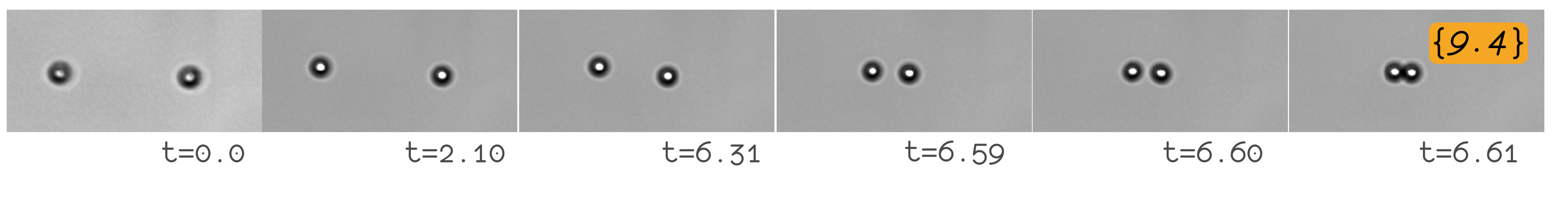
$$F_{visc} = 6\pi\eta RU$$

For a viscous medium, we first need to obtain the viscosity of the sample by using a gradient field. The viscous force is compared with the magnetic force.









{9.1} Object detection and separation measurement.
{9.2} Dipolar vs. Viscous Force (pico-newtons).
{9.3} Dipolar and Viscous Force (pN) vs. Beads Separation (μm). Highlighted: Exponential increase in dipolar force as distance decreases.
{9.4} Event Timelapse.

Next Steps

May-Jun 2018 Analysis of Beads in viscous mediums.
Jun-Jul 2018 Analysis of Cylinder and Beads configurations.
Jul-Sep 2018 Generalisation and Mathematical formulation.

References

Tavacoli, J. W., Bauër, P., Fermigier, M., Bartolo, D., Heuvingh, J., & du Roure, O. (2013). The fabrication and directed self-assembly of micron-sized superparamagnetic non-spherical particles. Soft Matter, 9(38), 9103-9110.

Bauër, P., Tavacoli, J., Pujol, T., Planade, J., Heuvingh, J., & Du Roure, O. (2017). A new method to measure mechanics and dynamic assembly of branched actin networks. Scientific reports, 7(1), 15688.