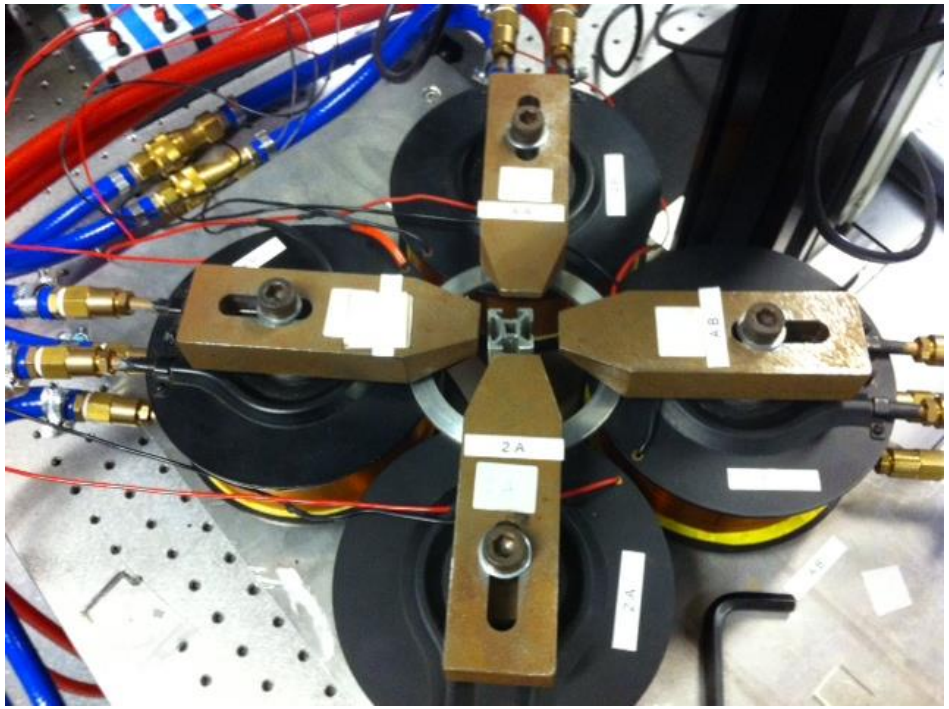
Microparcicle-enhanced mixing using time-dependent magnetic actuation in microfluidic chips



Evgeny Rebrov

Laboratory for Energy Intensified Reactor Engineering

Queen's University Belfast, Northern Ireland, UK

e.rebrov@qub.ac.uk

Queen's University Belfast

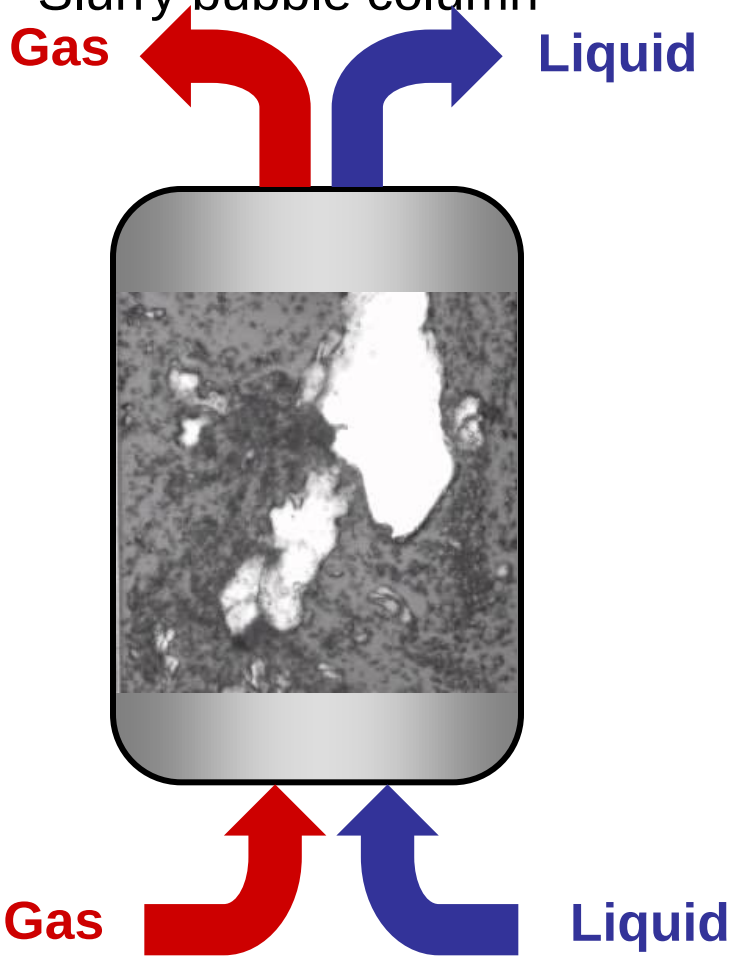
Outline

- ✓ New ways for process intensification
- ✓ Introduction to magnetic actuation
- ✓ Optimisation of mixing in laminar flow

Conventional G/L/S reactions

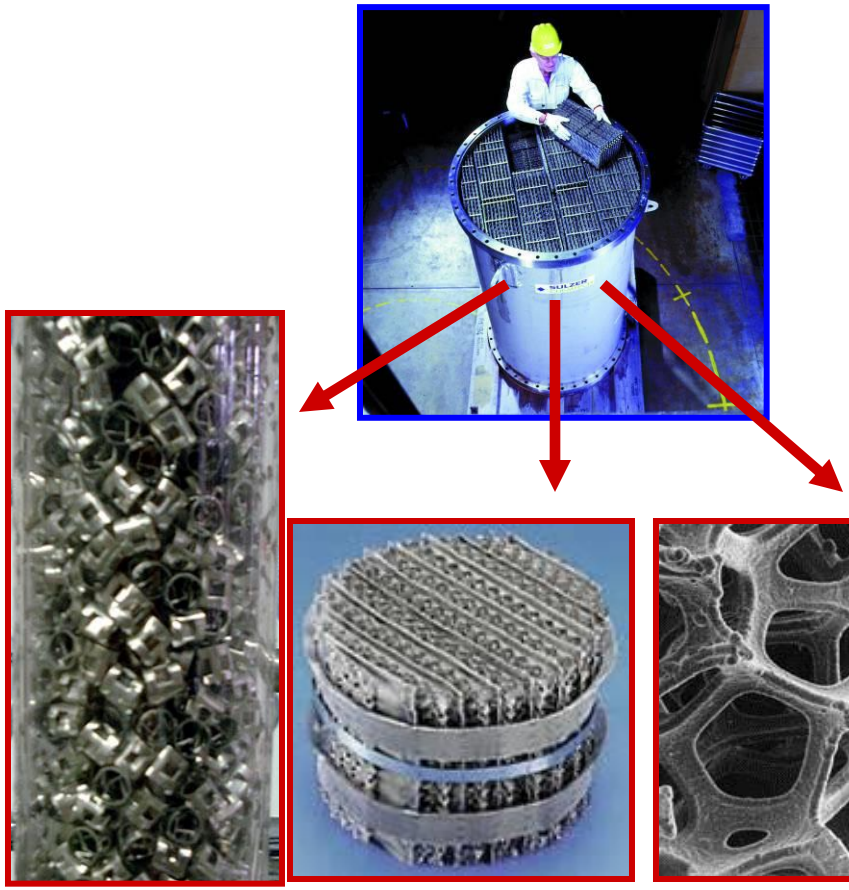
"Slurry" reactors:

- Stirred slurry tank
- Slurry bubble column

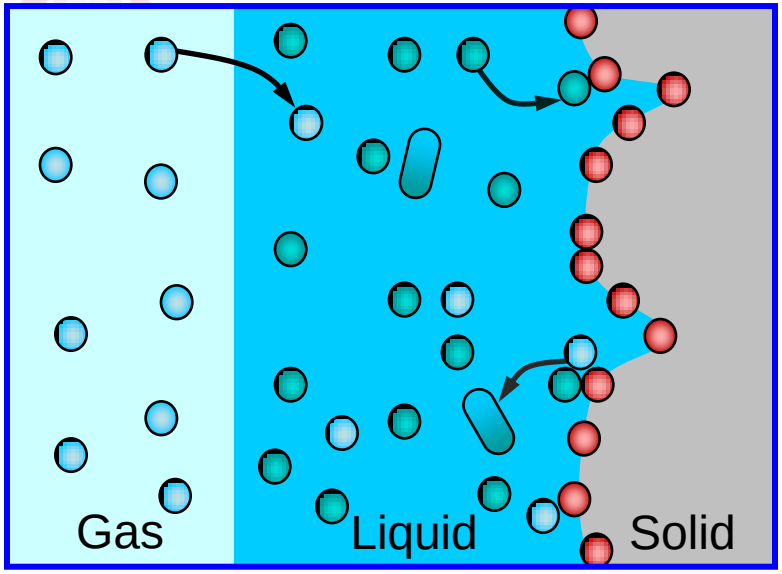


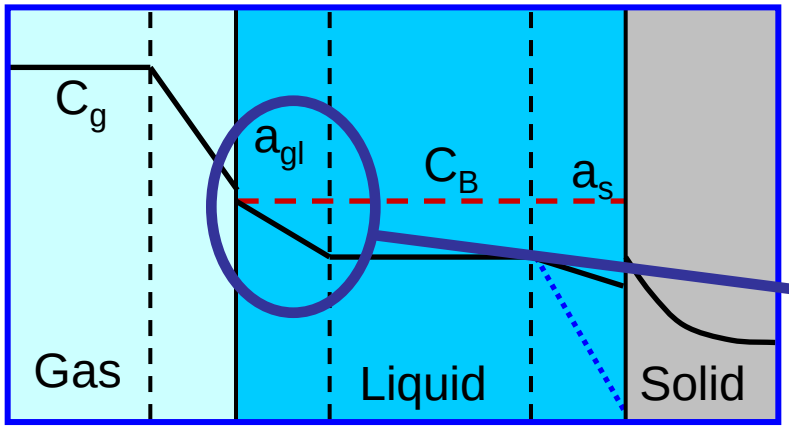
"Packed bed" reactors:

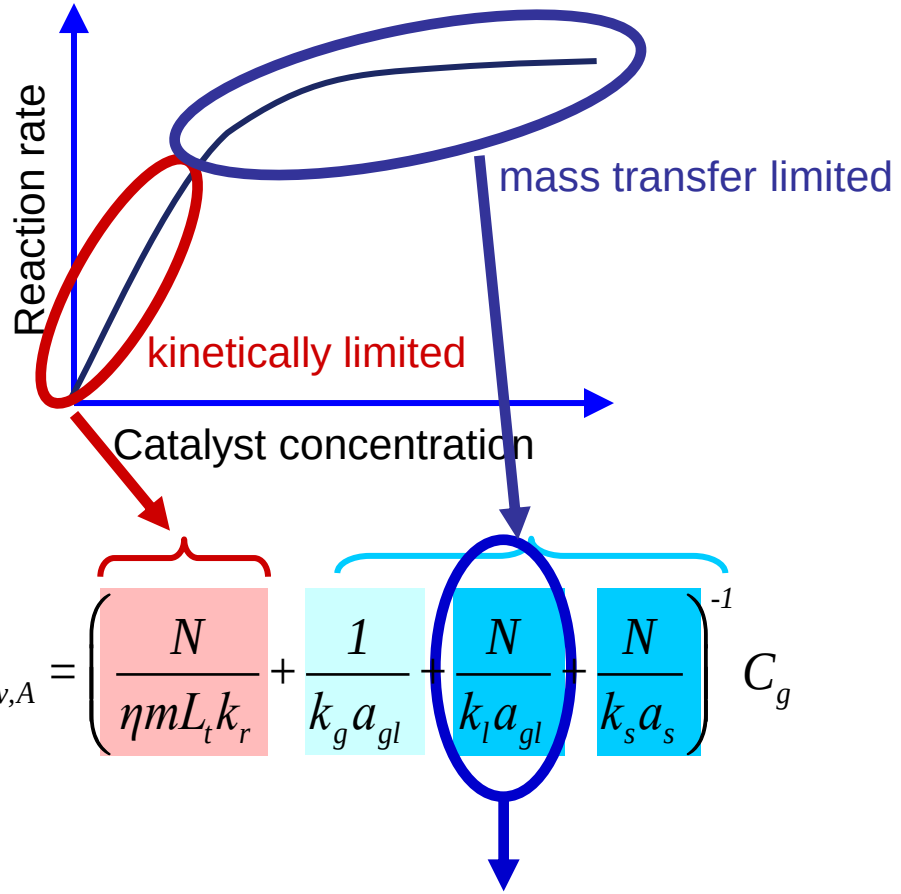
- Random packing
- Structured packing
- Foam packing



Conventional G/L/S reactions

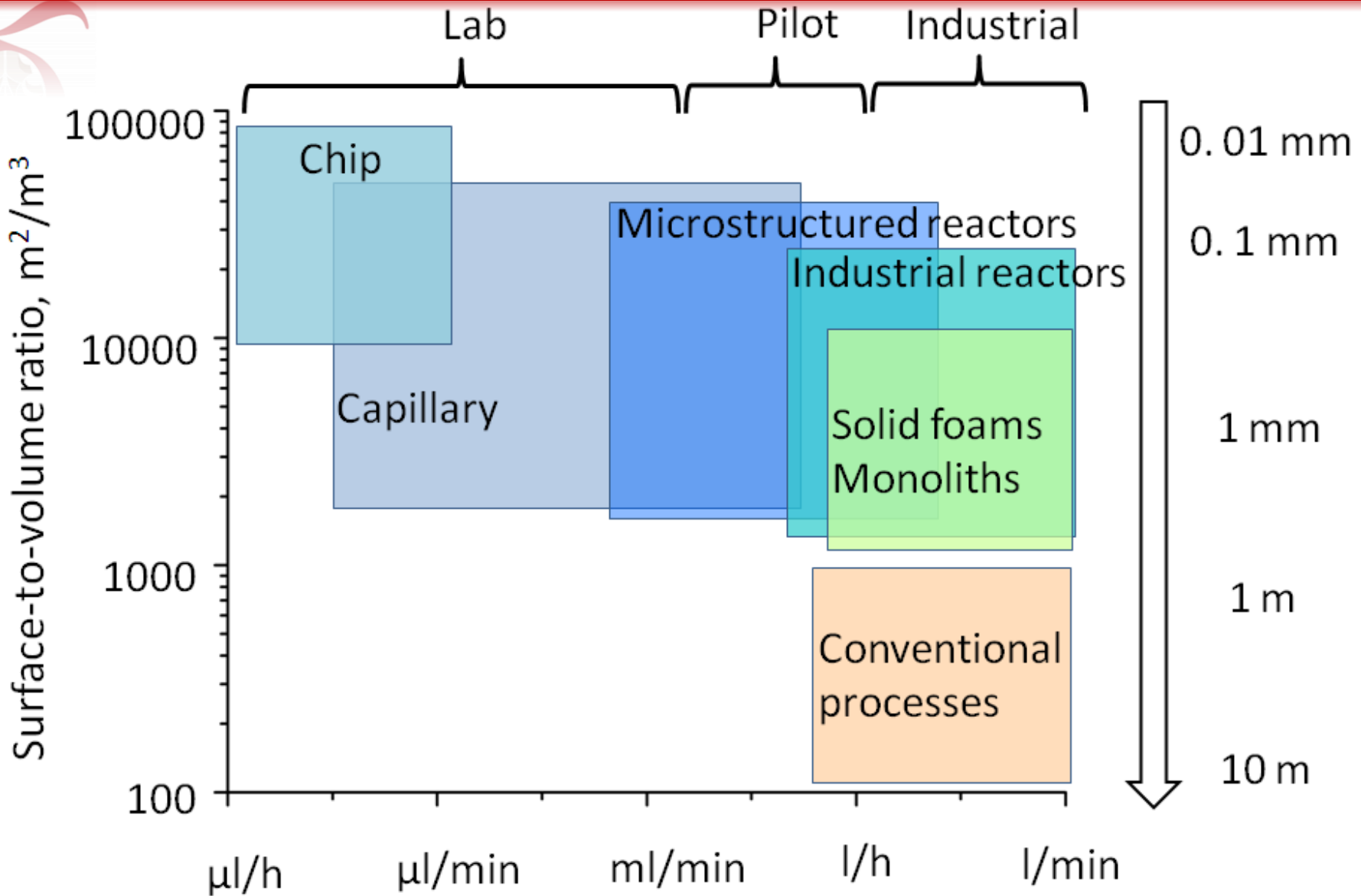






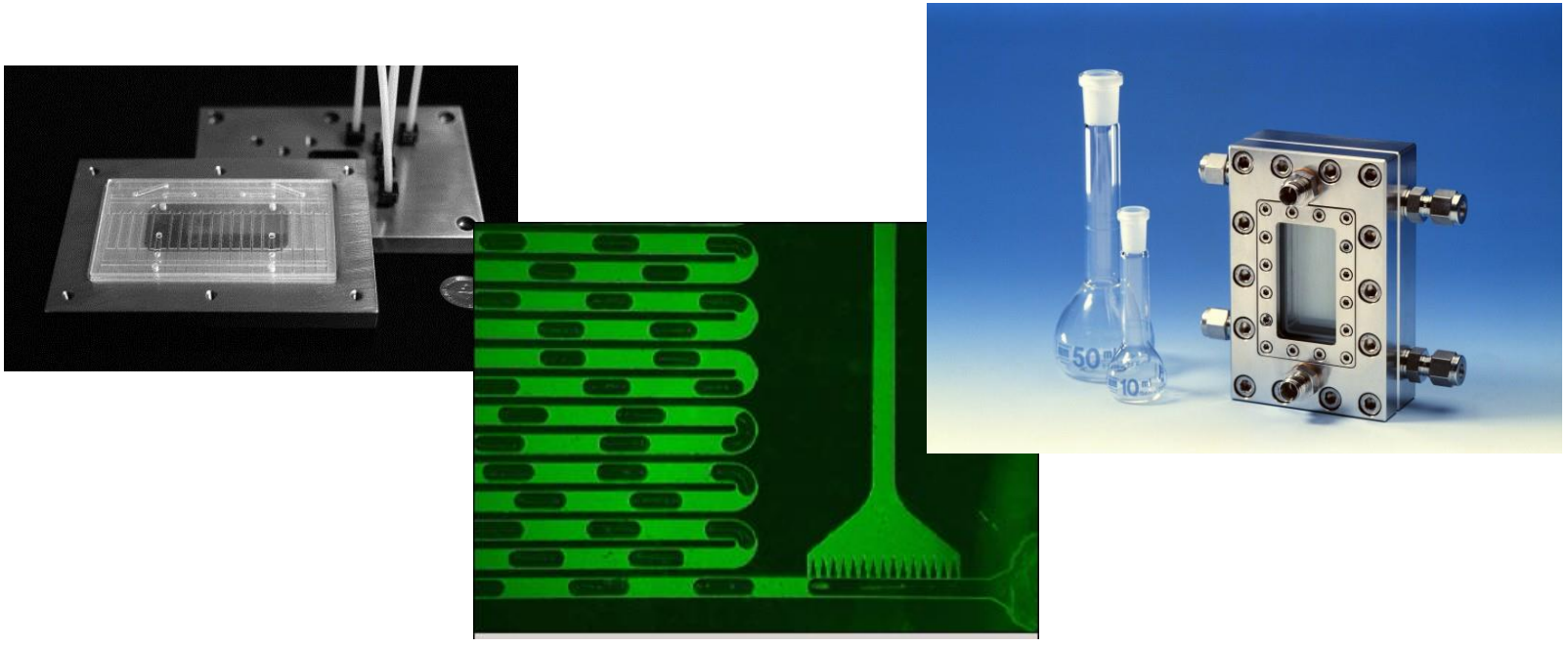
Rate limiting step for many gas-liquid-solid reactions!

Multiphase reactors for Process Intensification

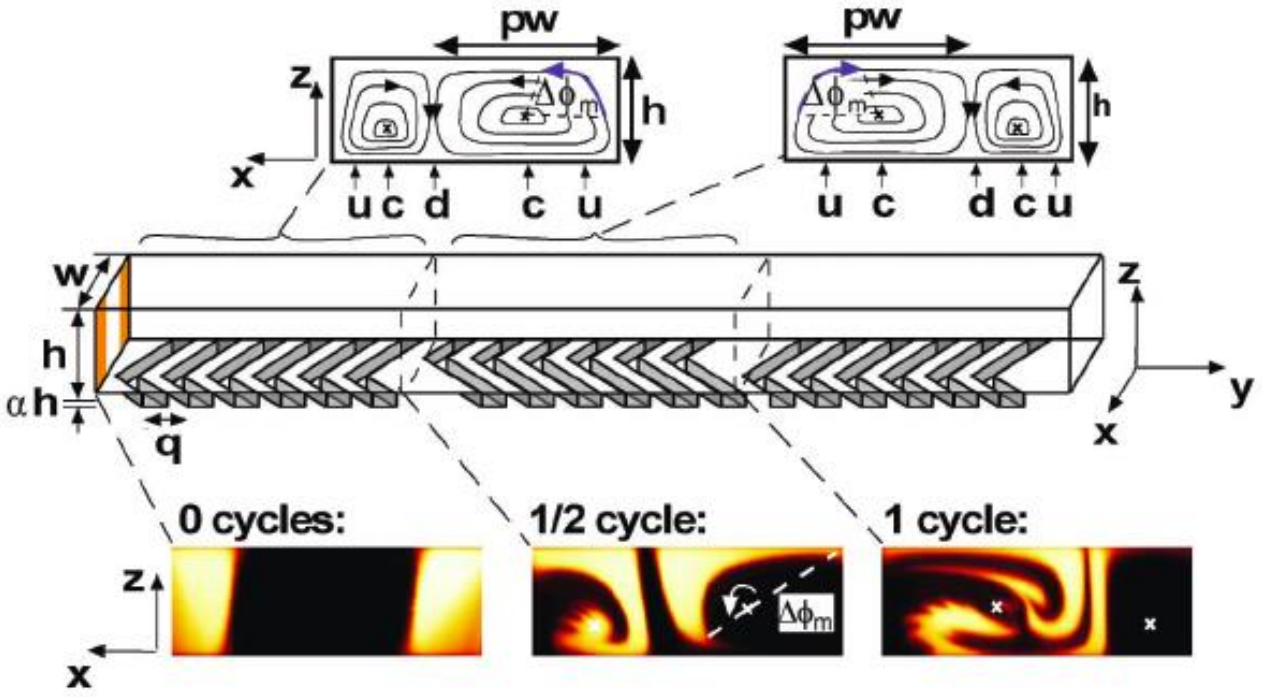


Backgrounds & features

- Micro-structured reactor channel diameters: sub mm to mm range
- Surface/Volume area: 1,000-50,000 m^2/m^3

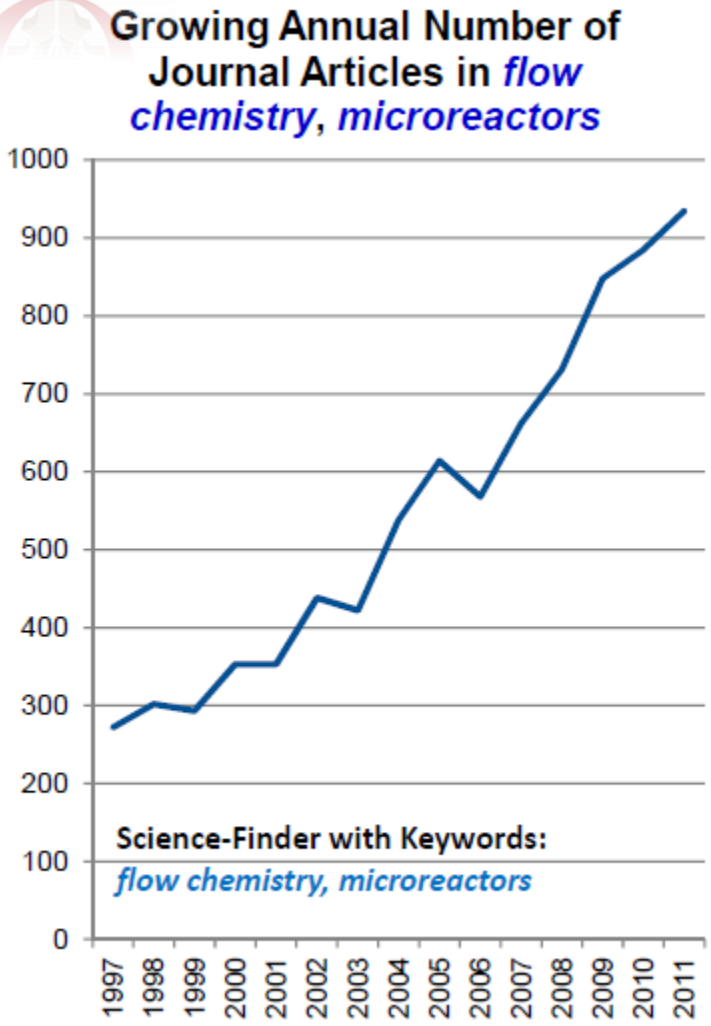


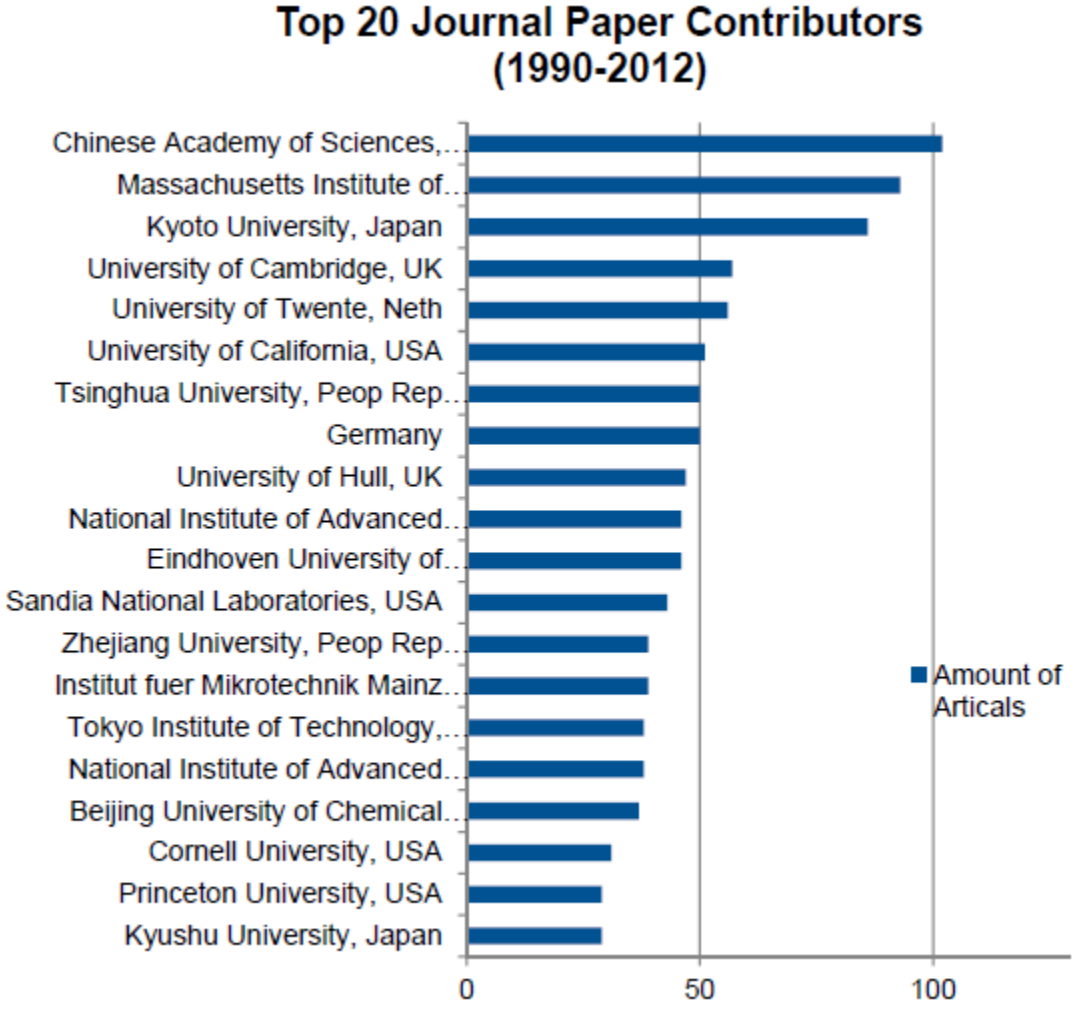
Structured plates



Stroock et al., Chaotic mixer for microchannels, Science 295 (2002) 647.

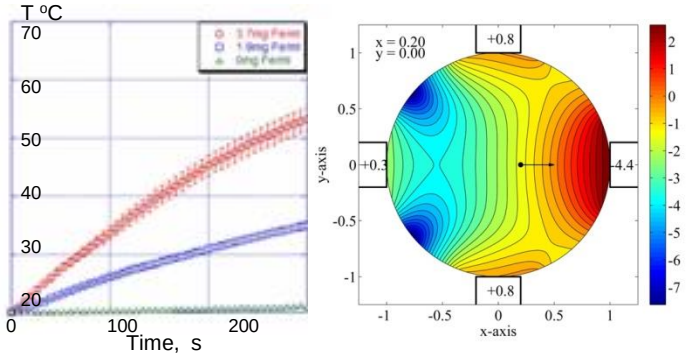
Flow chemistry & microreactors

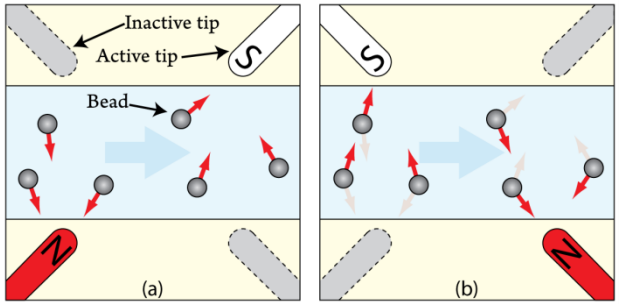




Our approach

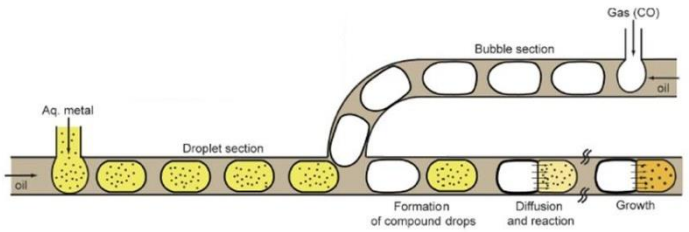
Heating & mixing via magnetic actuation



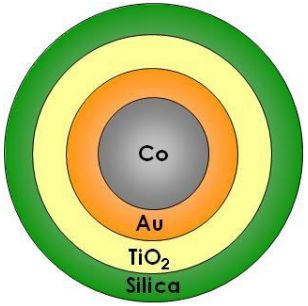


Aim: Design of new types of flow-through reactors for RF heating and magnetic actuation

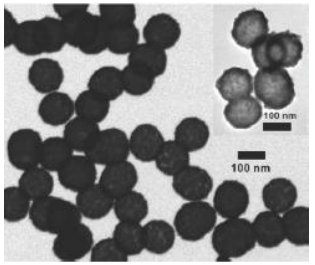
Microfluidic synthesis of magnetic NPs



Composite NPs



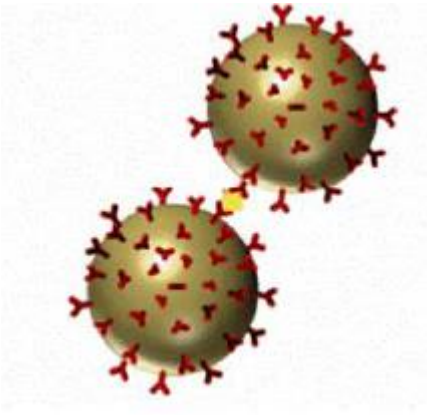
Monodispersity



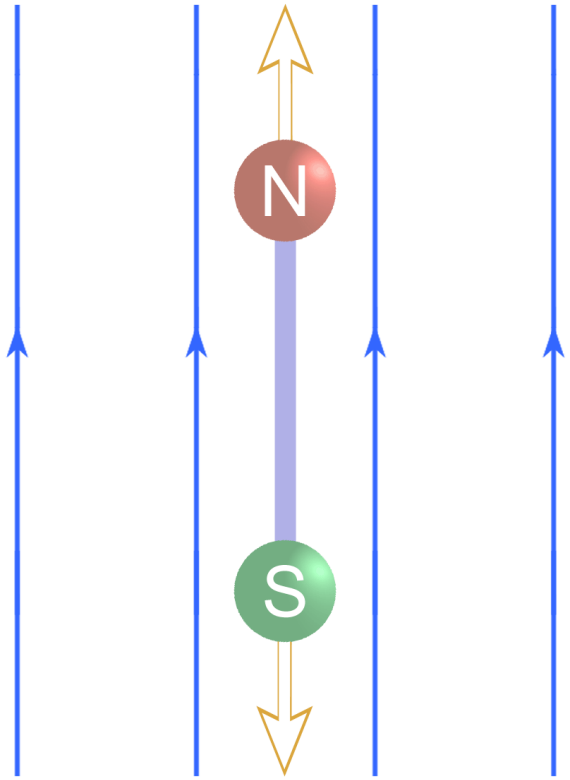
Aim: Development of strategies towards the synthesis of new composite NPs in a variety of architectures

Applications of magnetic microparticles

- to mix fluids,
- to selectively capture specific analytes (i.e. the biomarkers to be detected),
- to concentrate analytes,
- to transfer analytes from one solution to another
- to label analytes, to perform washing steps,
- to probe biophysical properties of the analytes

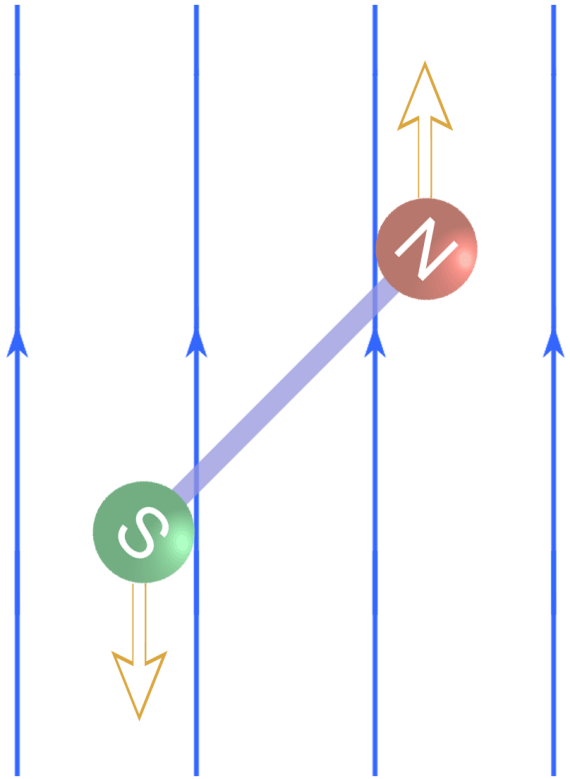


Magnetic actuation



- A uniform magnetic field tends to orient a magnetic dipole
- Uniform field does NOT exert translational force on dipole
- Forces on North and South pole balance

Magnetic actuation



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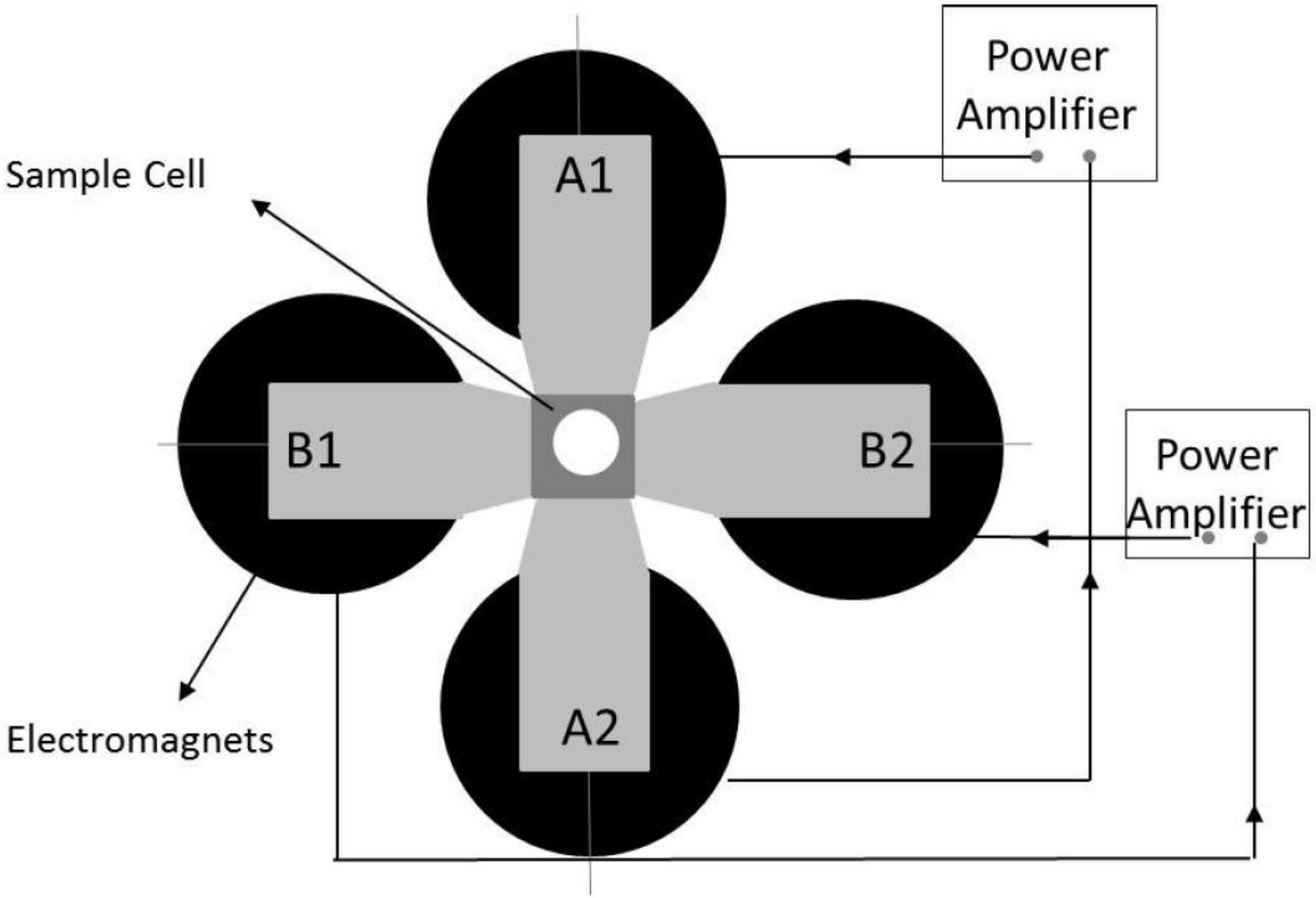
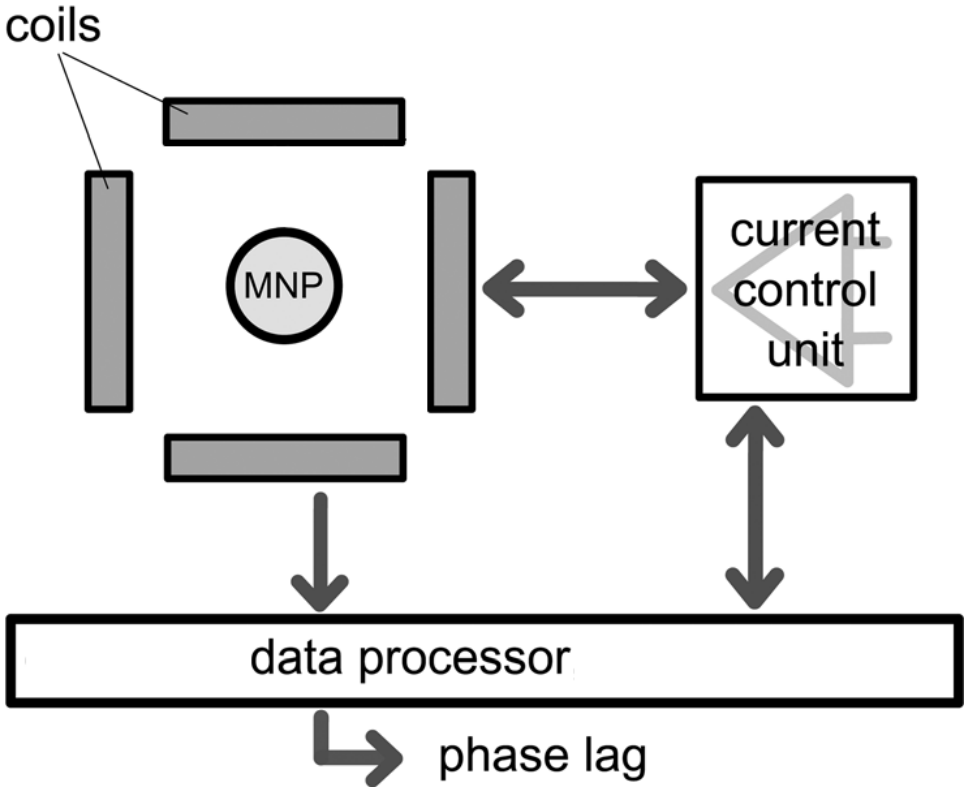
- Forces on North and South pole balance

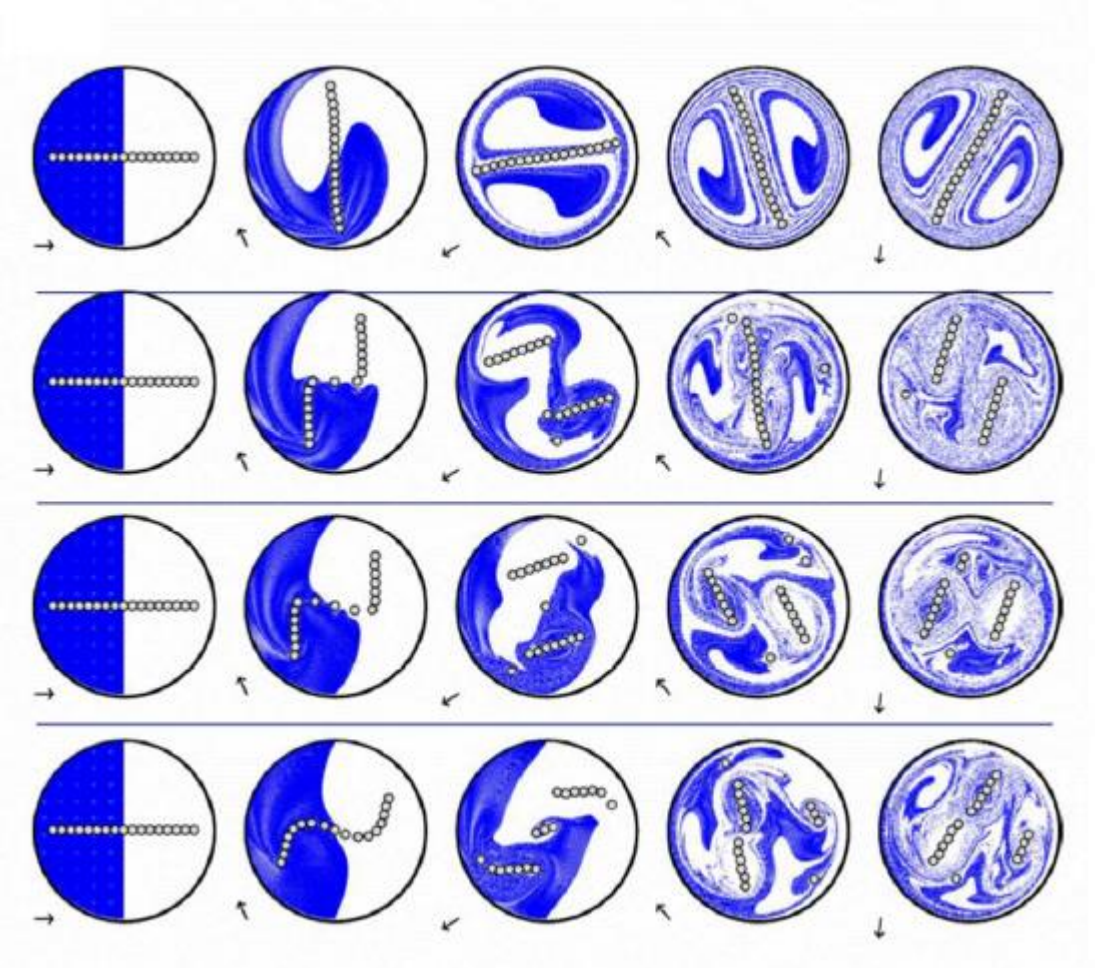
Quadrupolar magnetic actuation system



Magnetic actuation

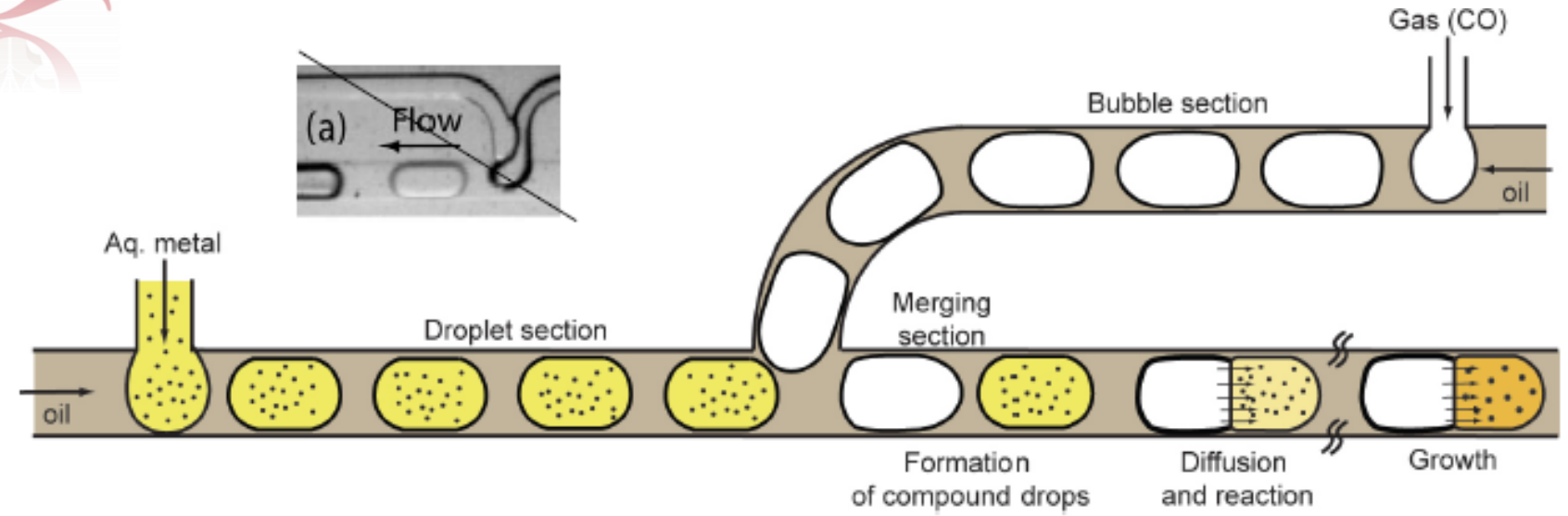


Particle chain in a rotating field of 3 Hz



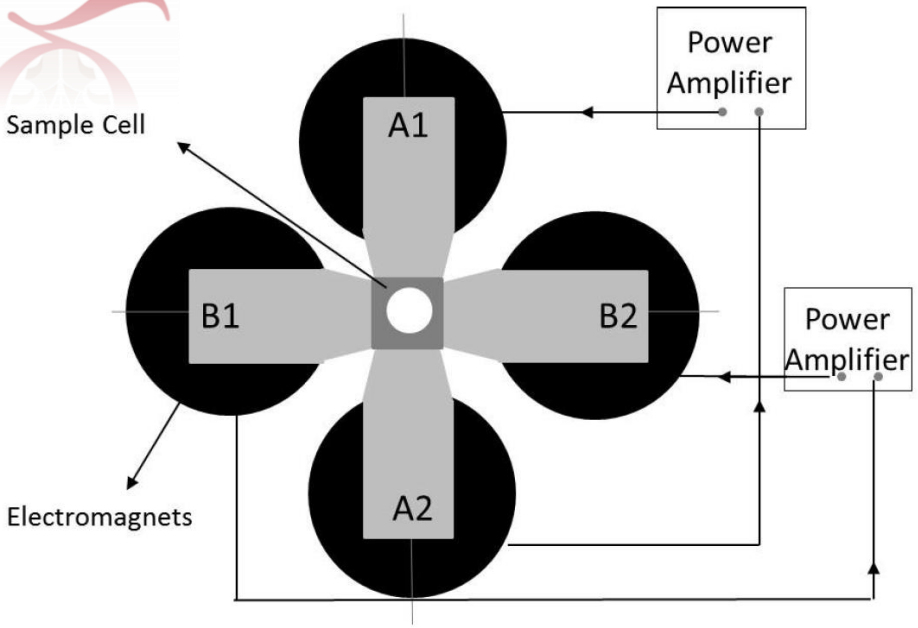
A. Van Reenen et al., Lab Chip, 2012

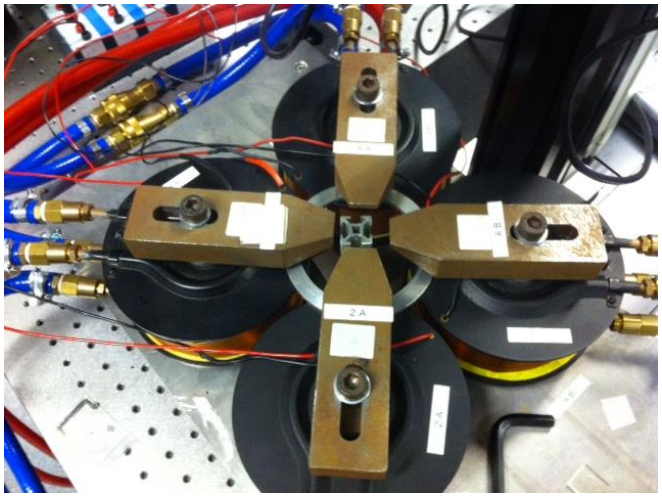
Synthesis of magnetic nano- and microparticles

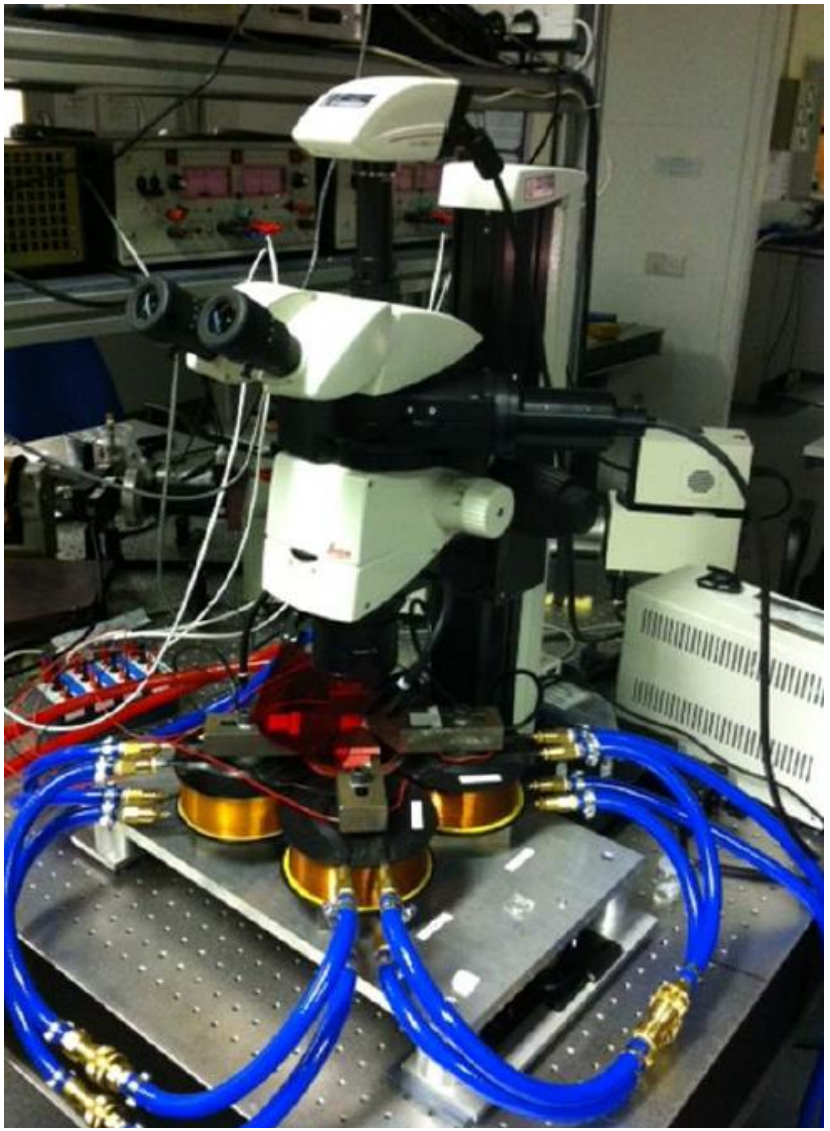


- CO – reducing agent
- Au nanocrystals – aqueous $HAuCl_4$
- Au nanoshells/nanoislands – aqueous Kgold and seeded silica
- Isolate the bubble formation zone from drop zone to prevent deposition at point of contact

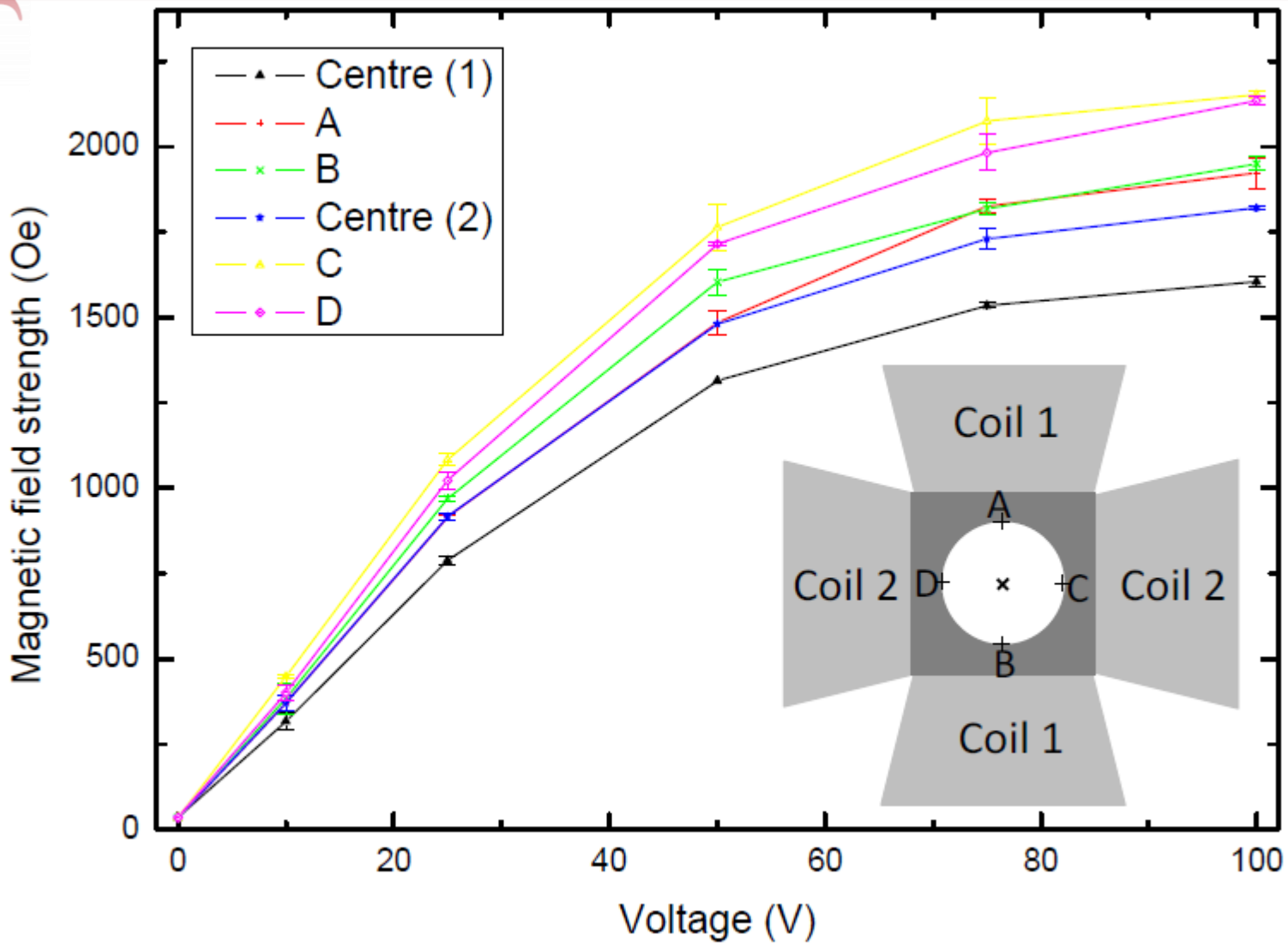
Quadrupolar magnetic actuation system



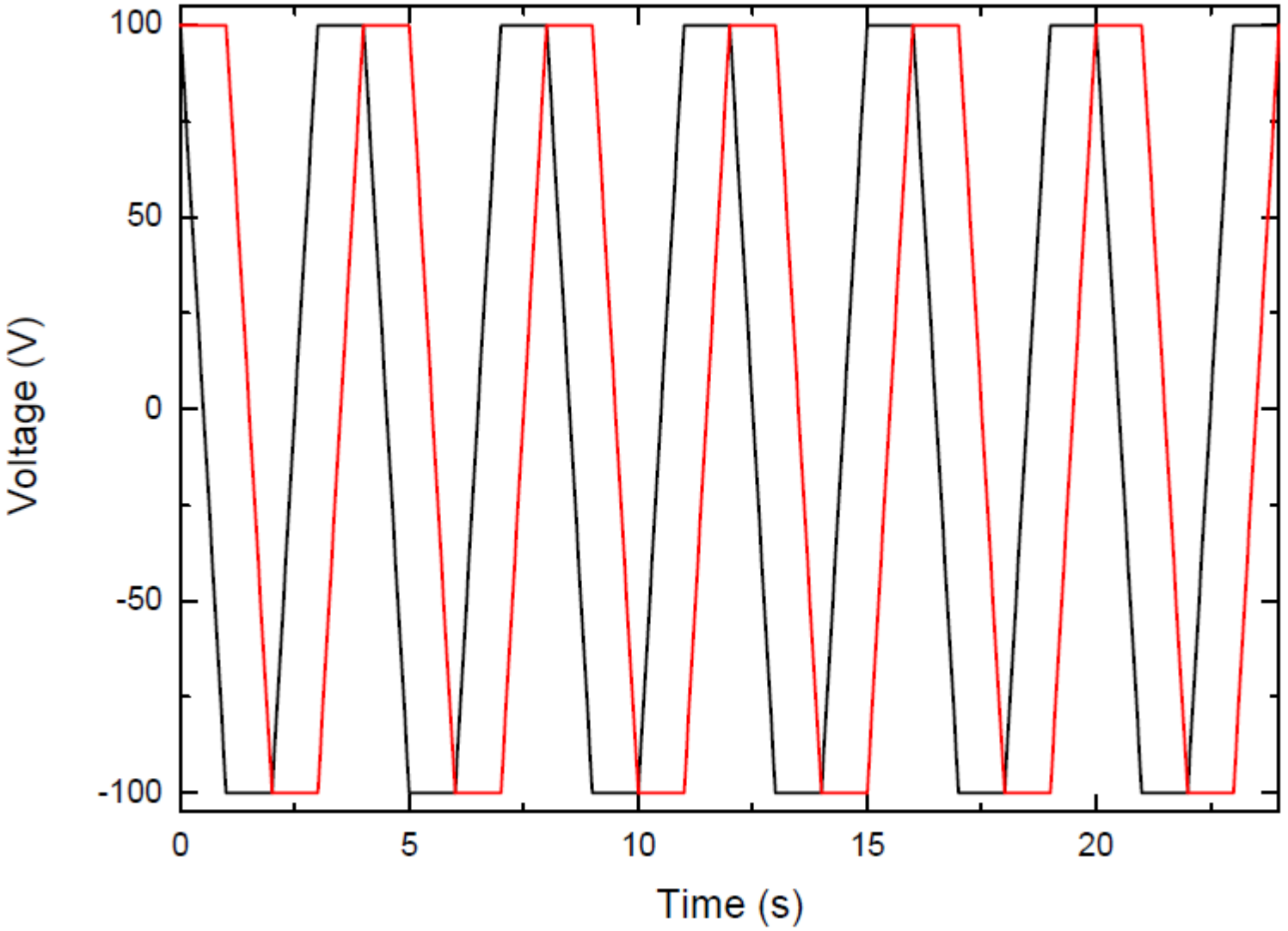




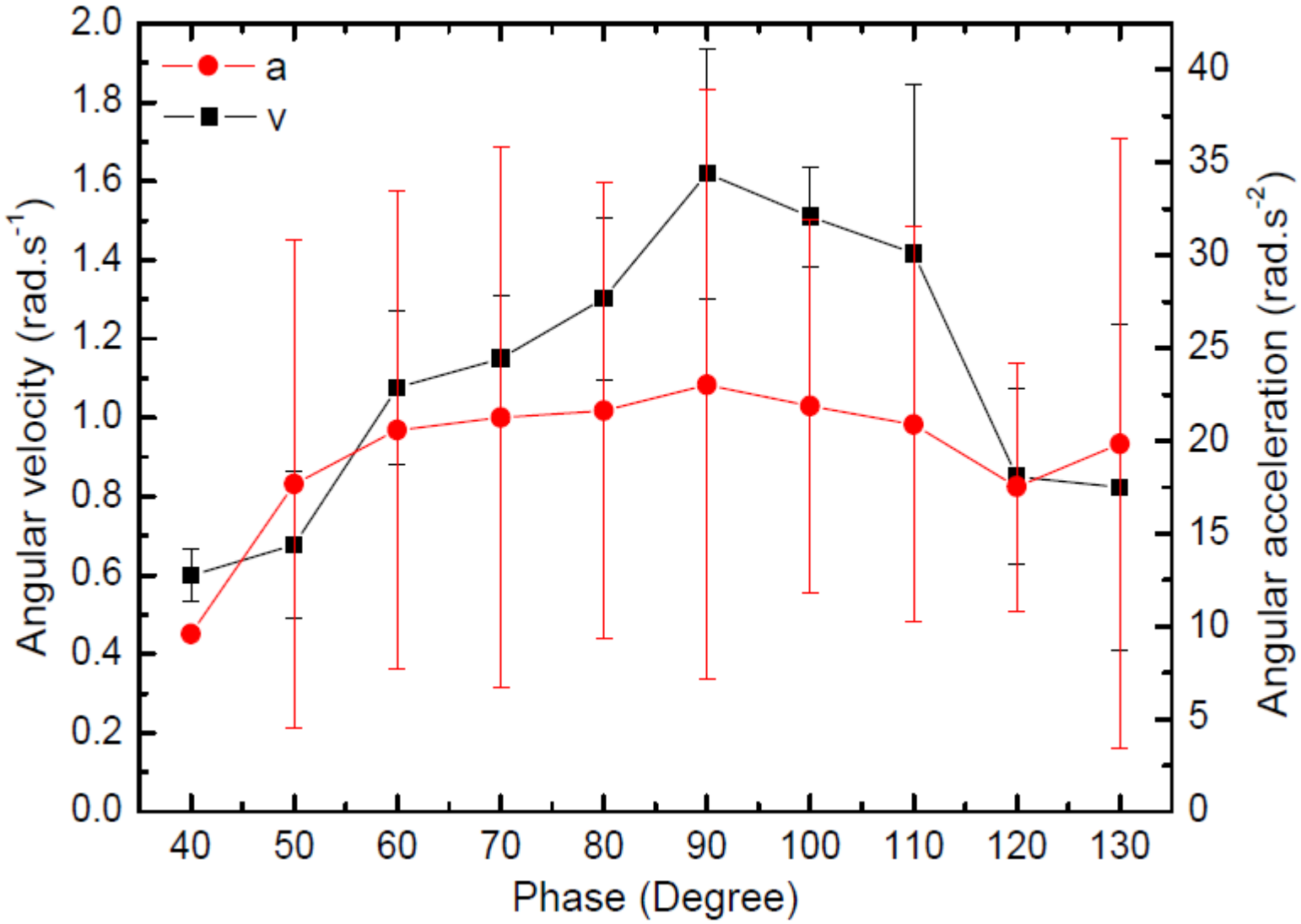
Magnetic field



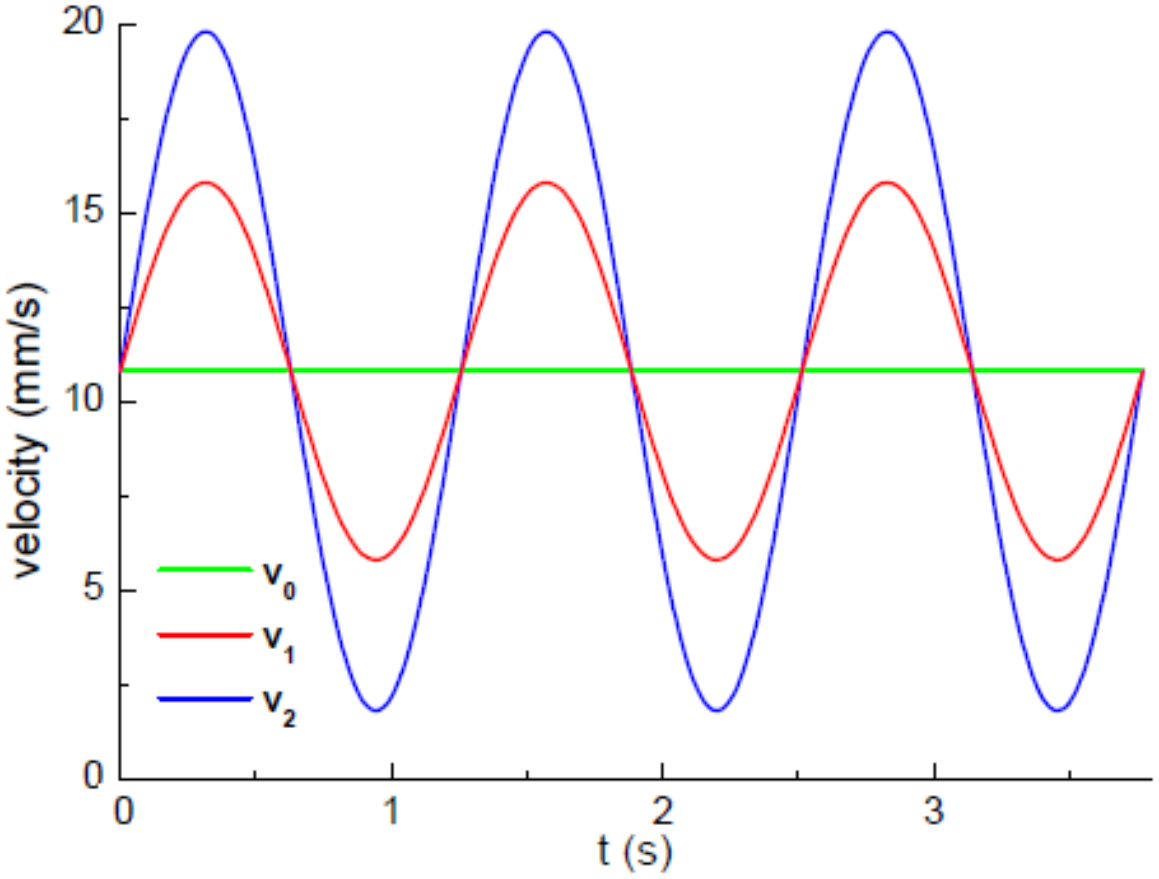
Actuation protocol



Effect of phase shift

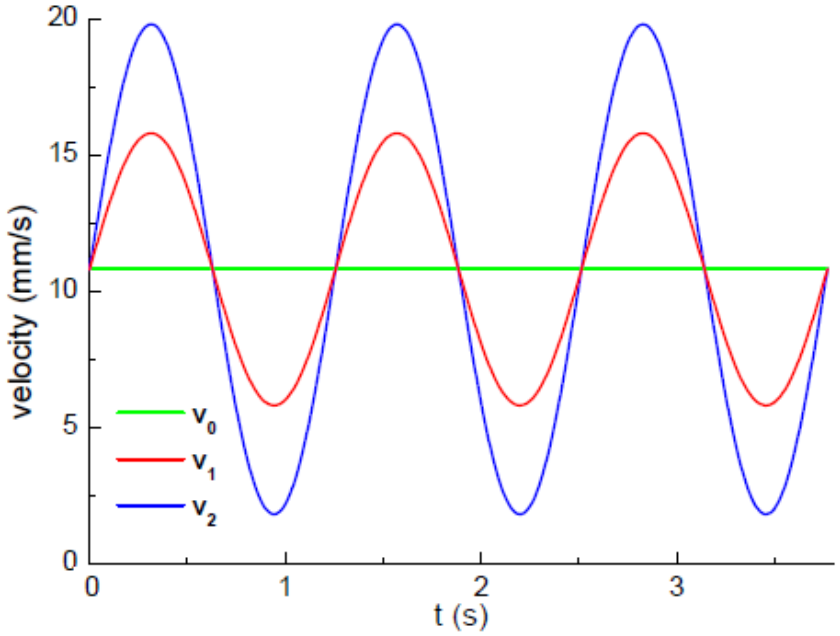


Velocity profiles



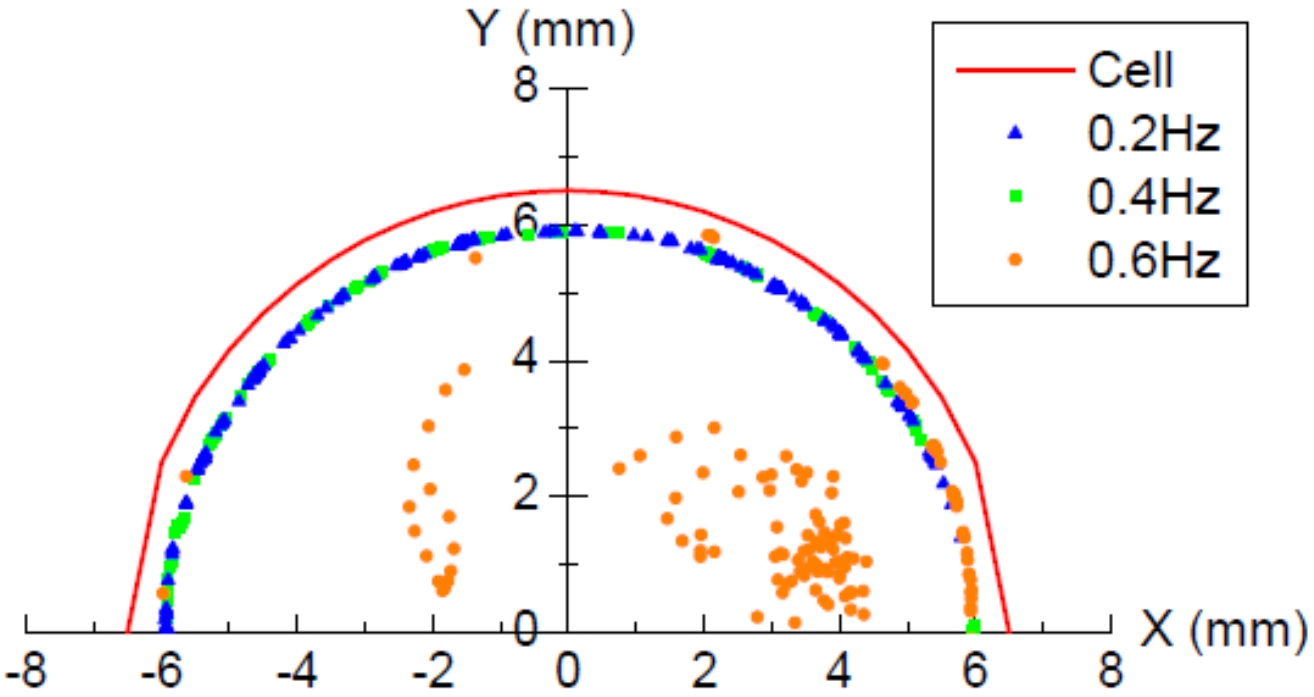
Steady vs transient motion?

$$Sh = 2 + 0.6 Re_p^{0.5} Sc^{0.33} \quad \text{for } Re_p > 1$$



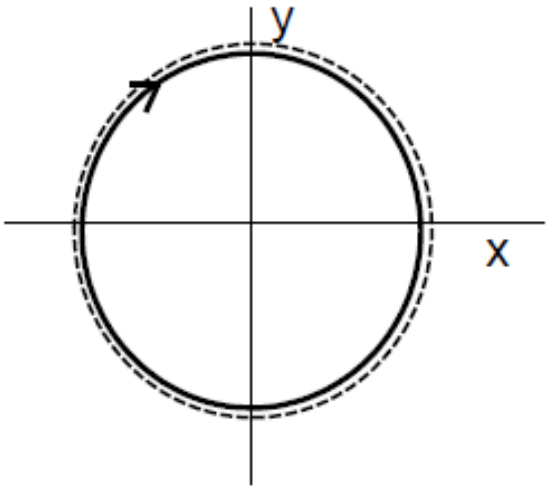
$\bar{v}$(mm/s)	$\overline{Re}$	$\overline{Sh}$
10.8	5.4	10.7
10.8	5.4	10.6
10.8	5.4	10.2

Particle trajectories



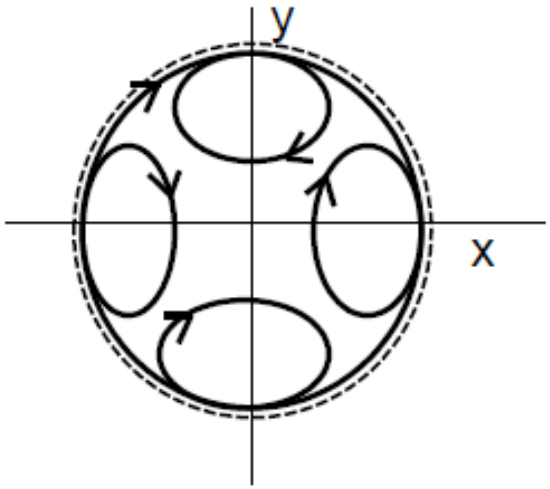
Particle trajectories

Mode I



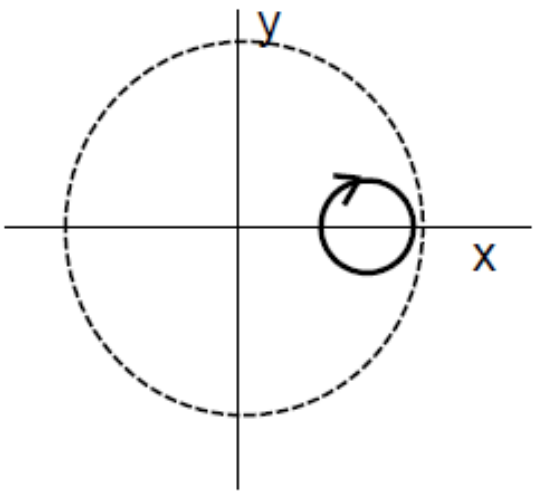
0.1-0.5 Hz

Mode II



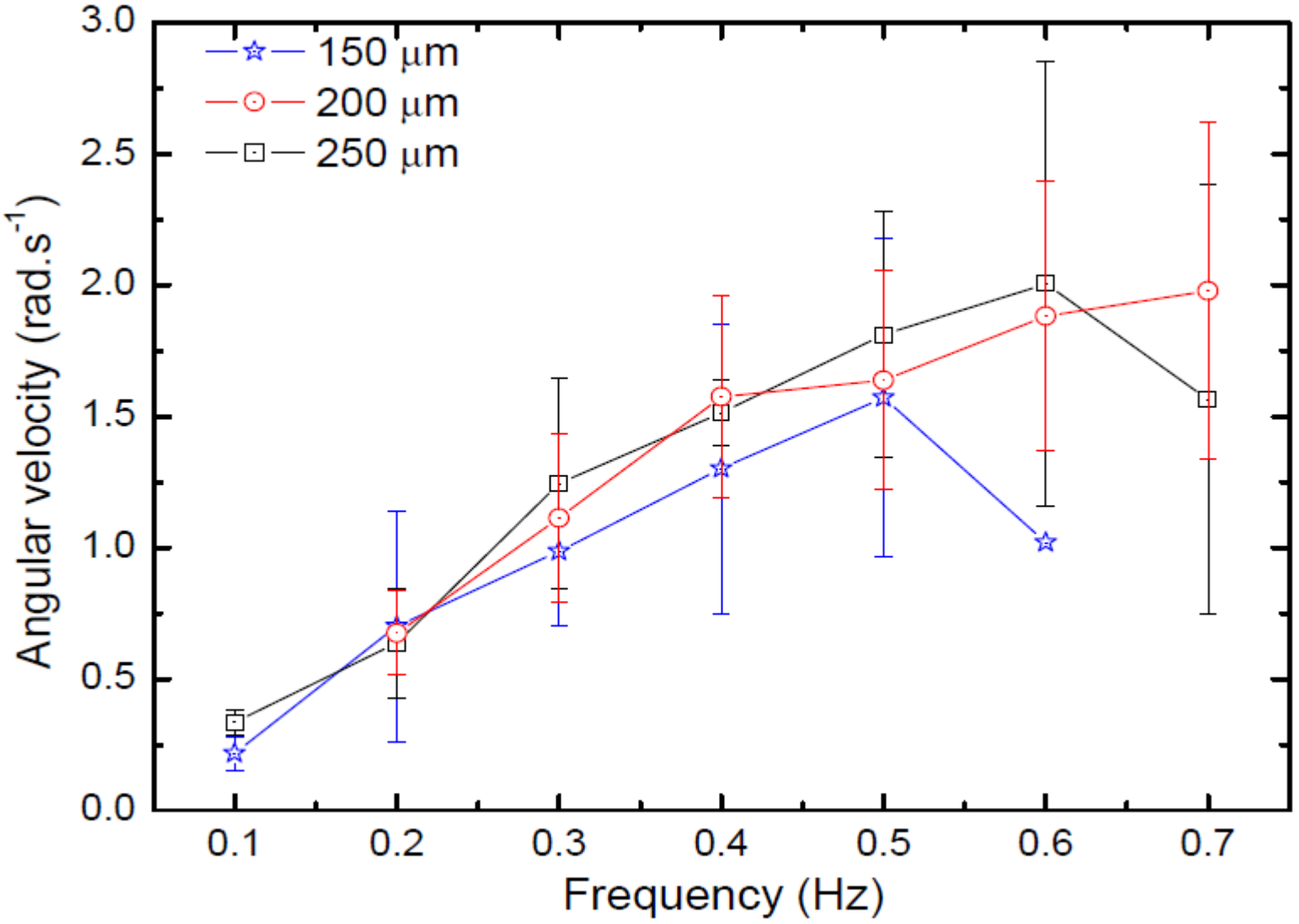
0.5-0.7 Hz

Mode III

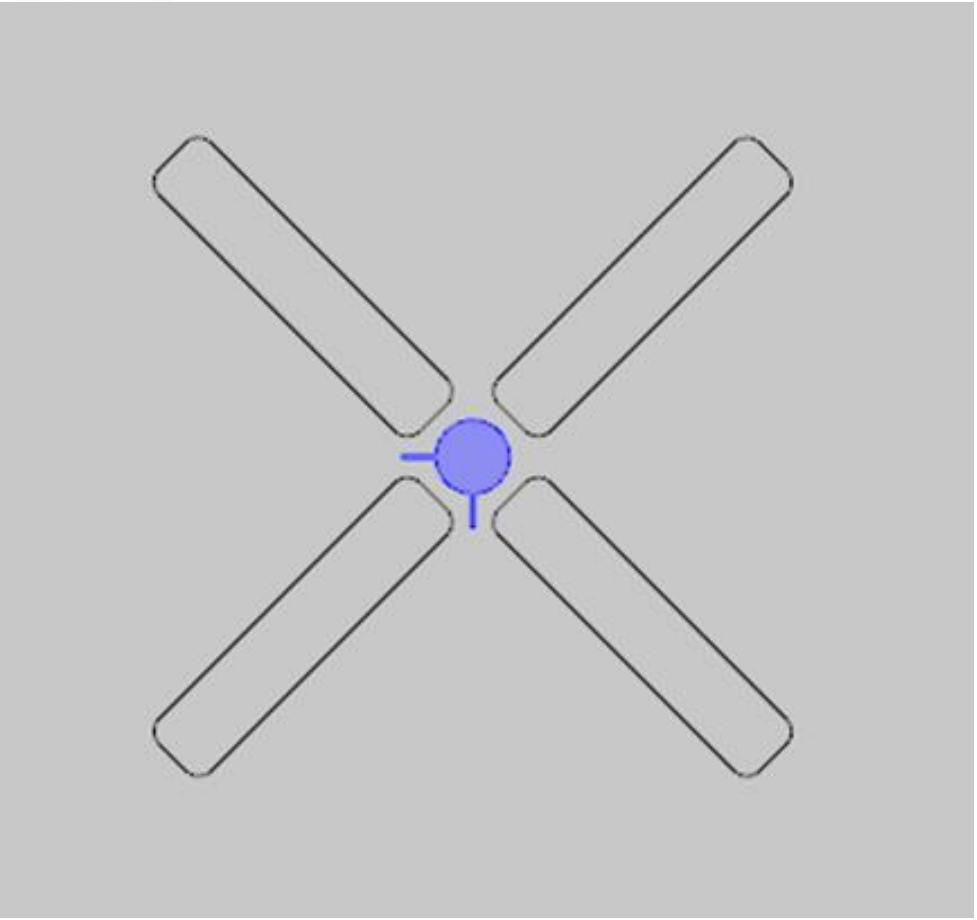


>0.7 Hz

Effect of particle size



CFD modelling



The model was created using three modules: (i) magnetic fields, (ii) laminar flow and (iii) particle tracing for fluid flow.

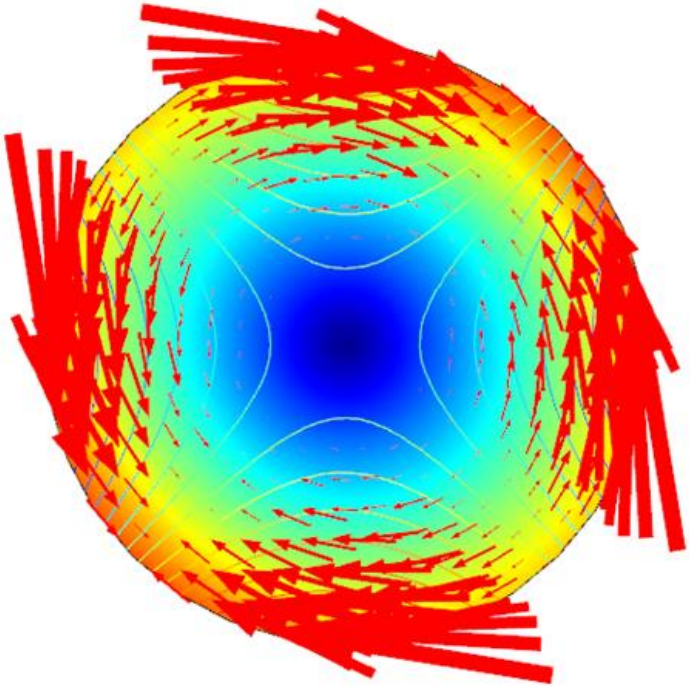
The four electromagnets were simulated using the multi turn coil domain tool within the magnetic fields module.

A sine function was specified for the applied voltage allowing input of the relevant parameters for the applied magnetic field.

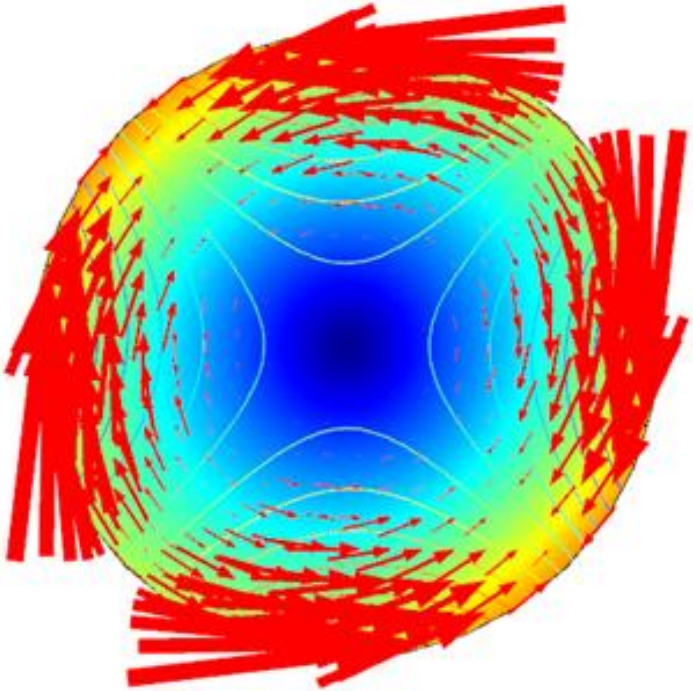
A transient time dependent study step allowed for an oscillating voltage and so a time dependent magnetic field distribution.

CFD modelling

t= 0, T/2

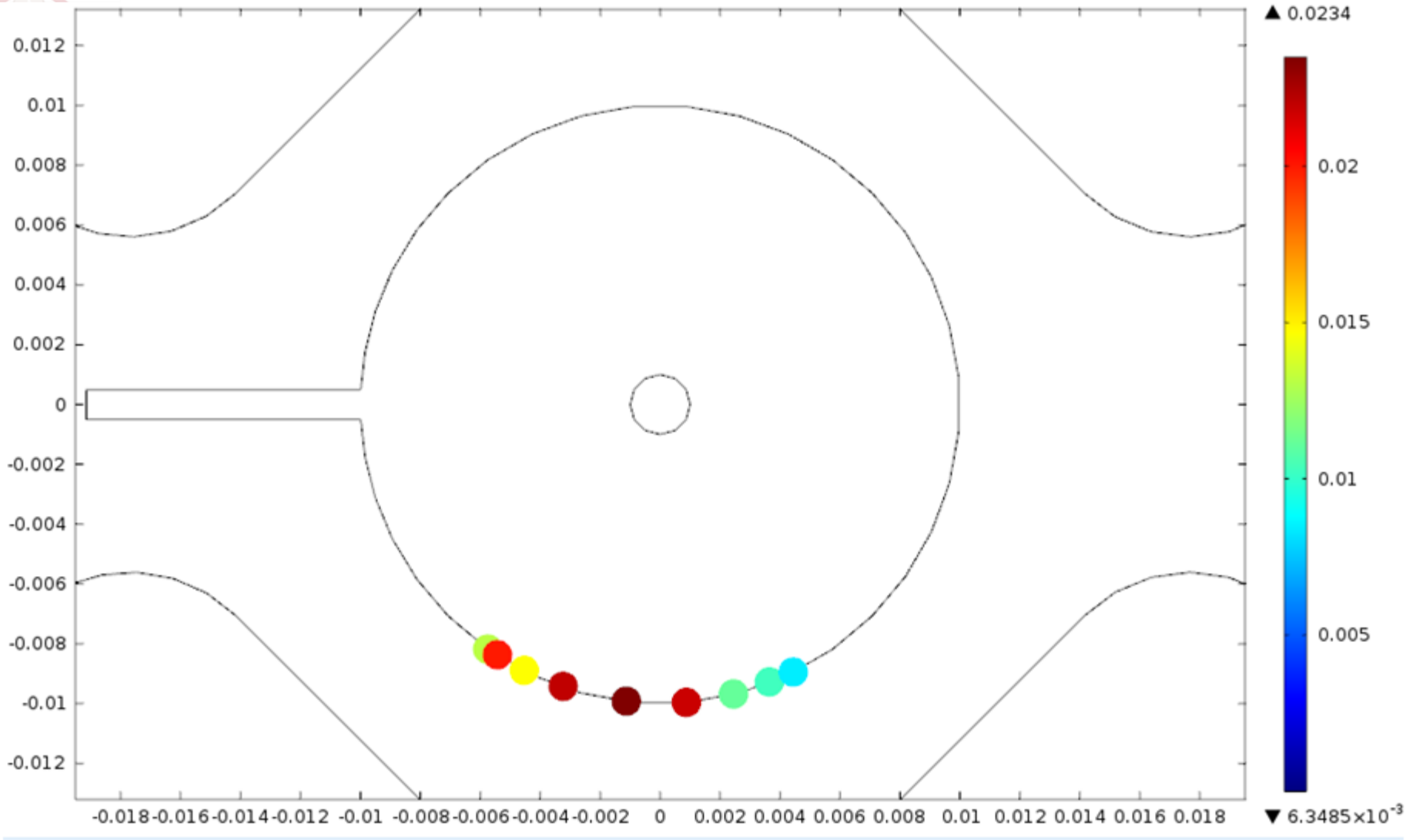


t= T/4, 3T/4

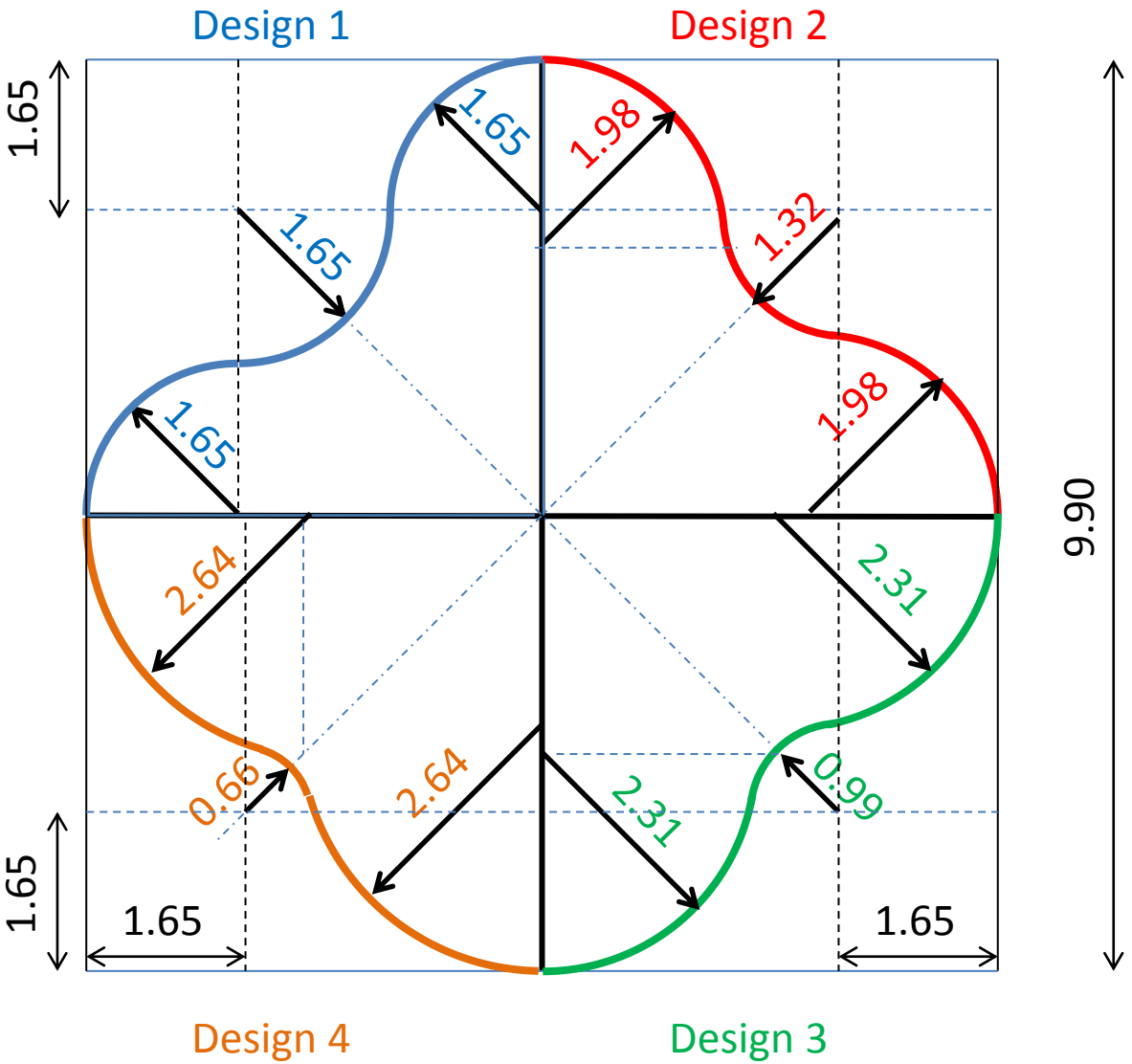


Colour: Magnetic field Contour: Gradient Arrows: Magnetic force

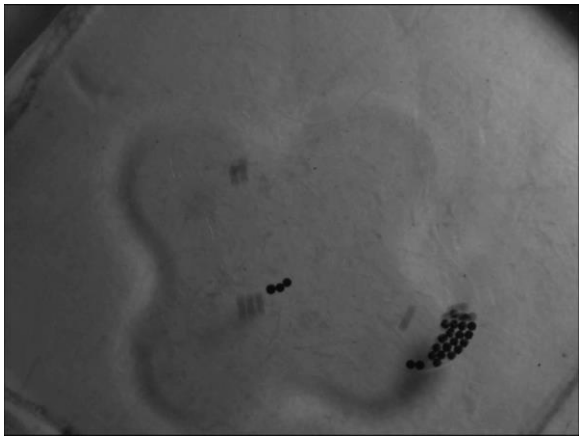
Particle trajectories

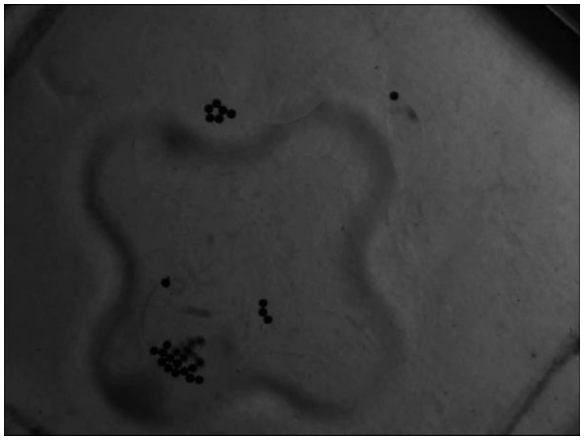


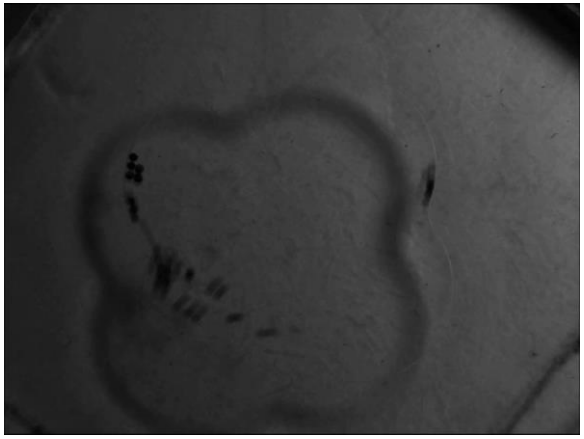
Design of the flow cell

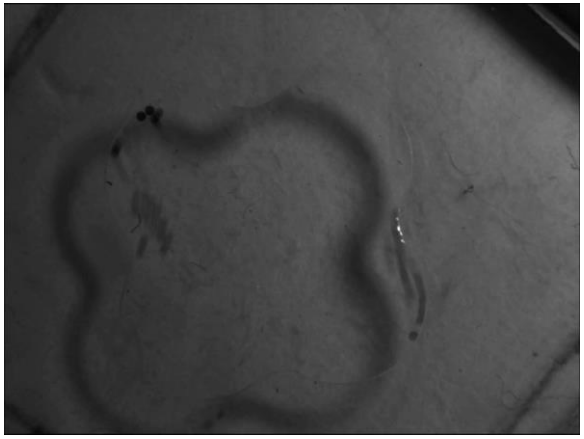


Particle trajectories









Thanks to

Dr Pengzhao Gao

Dr Taifur Rahman

Dr Erell Bonnot

Dr Volkan Degirmenci

Dr Robert Pollard,
Prof Robert Bowman,
Mr Philip Lisk

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