Collective motion of reciprocating self-propelled colloidal particles

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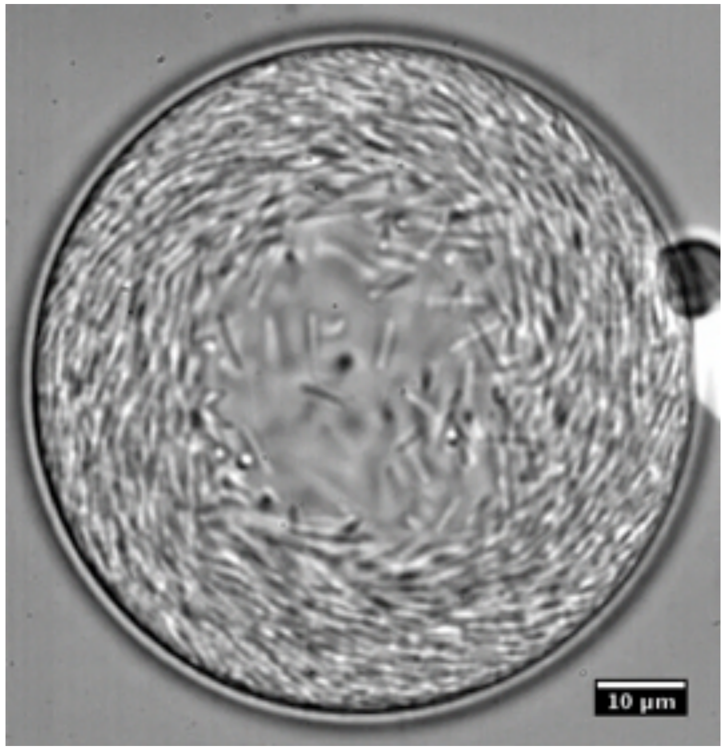
8th July, 2016@RIKEN-Osaka-OIST Joint Workshop 2016

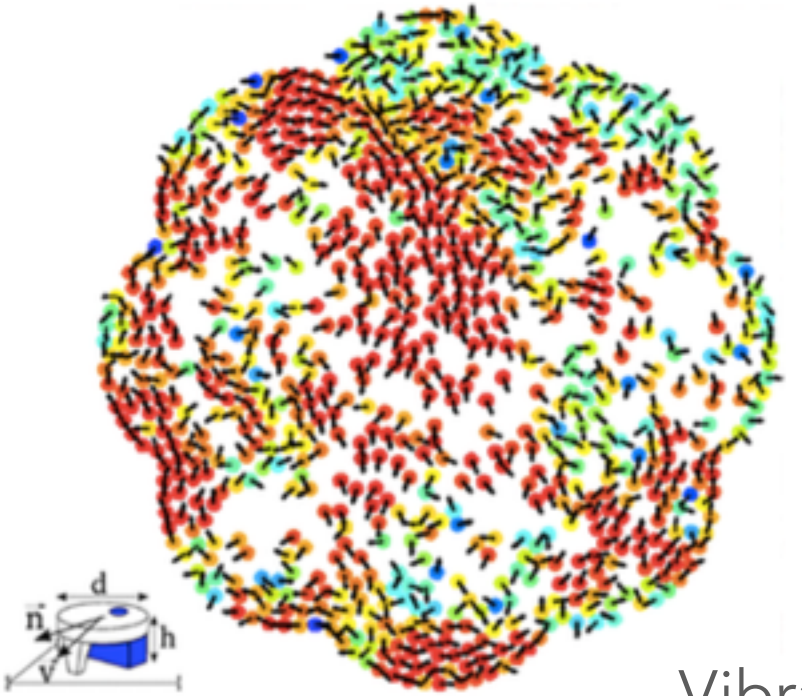
Self-propelled particle: motivation

fish school

bird flock

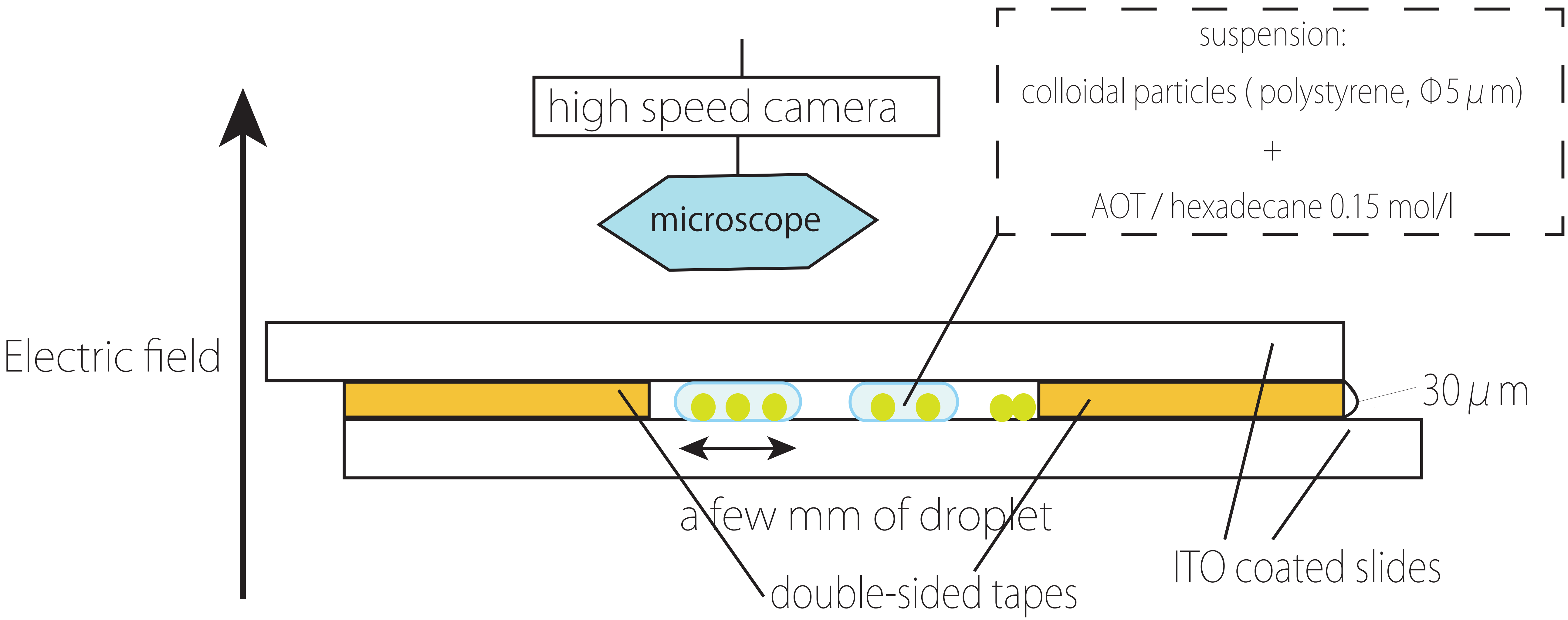


Bacterial suspension



Vibrated disks

Experimental Setup: colloidal particles rolling on a electrode

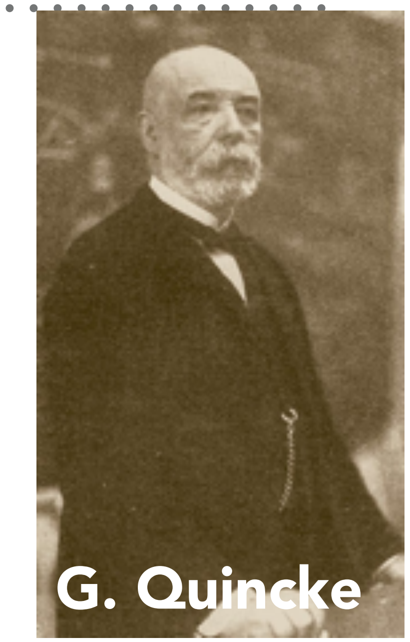


How is the mechanism of propulsion?

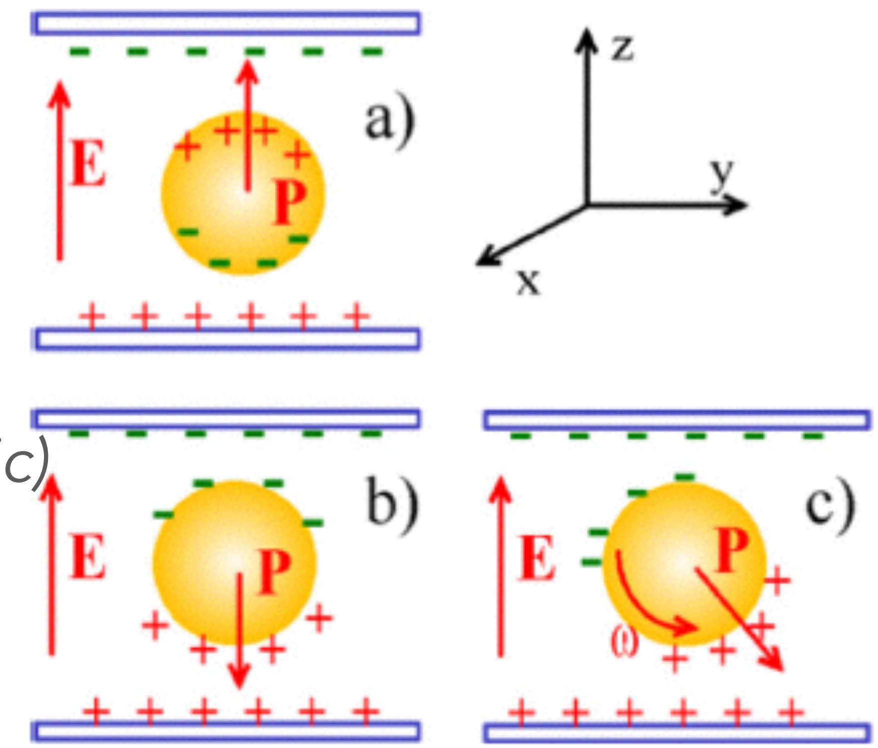
https://de.wikipedia.org/wiki/Georg_Hermann_Quincke
Original paper: G. Quincke, Ann. Phys. Chem. 59, 417-486 (1896).
N. Pannacci et al., Phys. Rev. Lett. 99, 094503(2007).

Rolling mechanism: the Quincke effect

Charge relaxation time $\tau = \epsilon/\sigma$ *=(dielectric constant)/(conductivity)*



$\tau_l > \tau_p$



stable

unstable

$\sigma_l \gg \sigma_p$ *(dielectric)*

→ $\tau_l < \tau_p$

Electric torque $\boldsymbol{P} \times \boldsymbol{E}$

surpass the viscous torque in $\mathrm{E}_0 \geq E_c$

start to rotate!

induced by the surface charge

$$\begin{cases} \dfrac{d\boldsymbol{P}}{dt} + \dfrac{1}{\tau}\boldsymbol{P} = -\dfrac{2\pi\epsilon_0 a^3}{\tau}\boldsymbol{E}_0 + \boldsymbol{\Omega} \times (\boldsymbol{P} - 4\pi\epsilon_0 a^3 \chi^\infty \boldsymbol{E}_0) \\ I\dot{\boldsymbol{\Omega}} = \boldsymbol{P} \times \boldsymbol{E}_0 - \mu_r^{-1}\boldsymbol{\Omega} \end{cases}$$

$\tau \sim 1\mathrm{ms}$

(instantaneous)

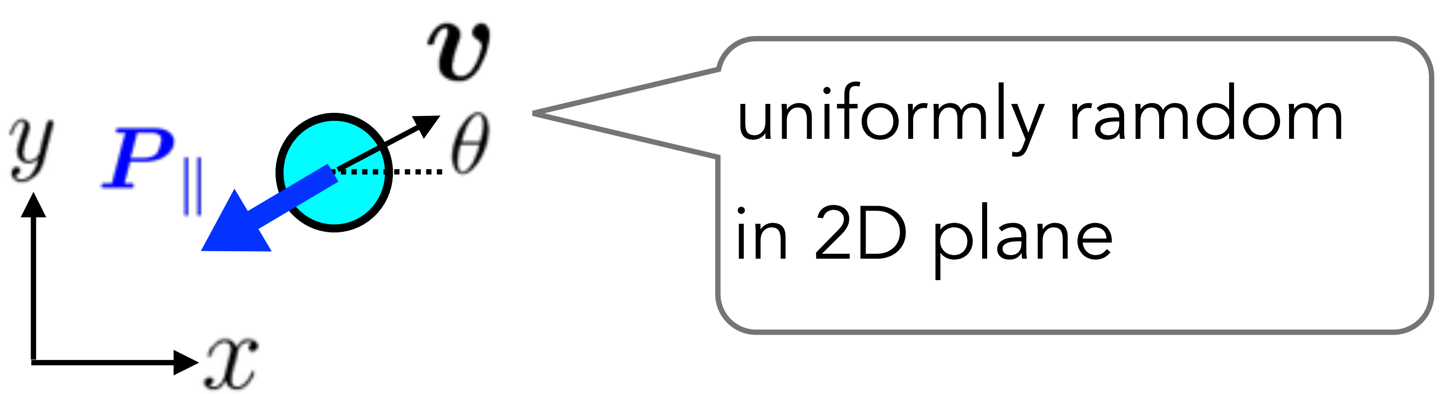
(electric torque) (viscous torque)

steady stable sol.: steady rotation

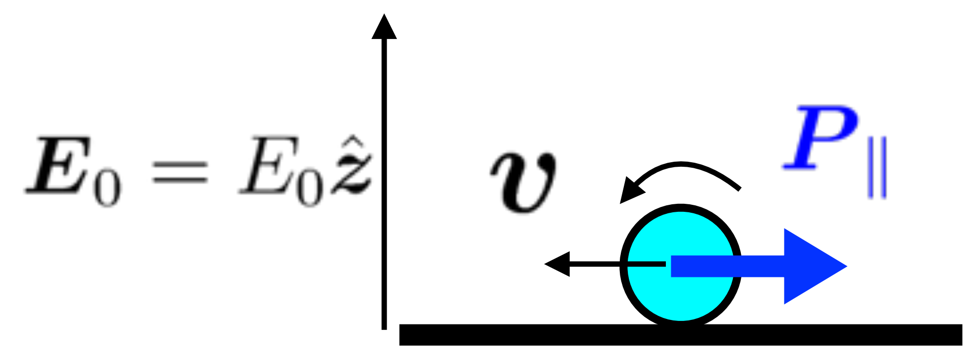
$$\Omega = \frac{1}{\tau}\sqrt{\left(\frac{E_0}{E_Q}\right)^2 - 1}$$

Properties of Quincke rollers

➤ relax in 1ms and then constant speed



$$\boldsymbol{v} // -\boldsymbol{P}^{\sigma}_{\parallel} (= -\boldsymbol{P}_{\parallel})$$



⚠ NOT electrophoresis. Always external field ⊥ propelling direction

- typical speed: $100 \sim 1000 \mu\text{m/s}$
- cf. speed of bacteria $\sim 20 \mu\text{m/s}$

✓easy preparation

✓easy to control propulsion speed

✓relaxation time to steady state is small

- Other slides are deleted (unpulblished).