Reverse Osmotic Effect in Active Matter

Hyeongjoo Row* and John F. Brady
Department of Chemical Engineering, California Institute of Technology, Pasadena, CA 91125 USA

Fluids in a suspension tend to flow from dilute to concentrated region: the osmotic effect. It might not be true in active matter systems.

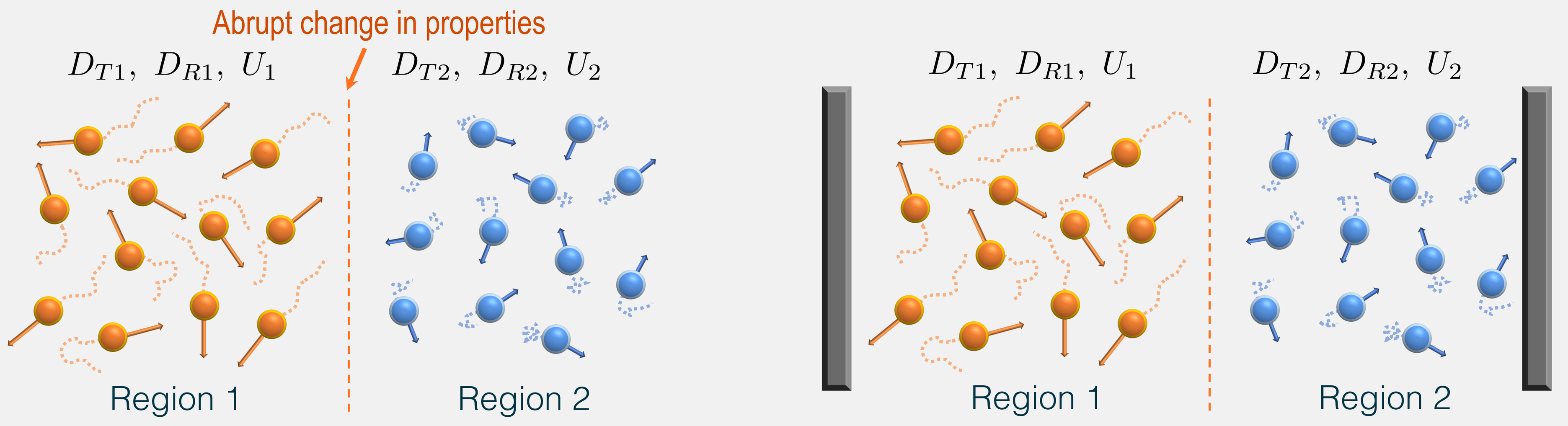
Introduction

Active Matter

Active matter is characterized by its ability to convert energy from surroundings to its own mechanical energy for self-propulsion. Fish, birds, motile bacteria, and even we are active matter!

Problem Description

One of the most fundamental questions we can ask about active matter systems is what would happen if active matter has spatially varying speed. We investigate results of **step change in self-propelling speed and diffusivities** in dilute active matter system at colloidal scales.



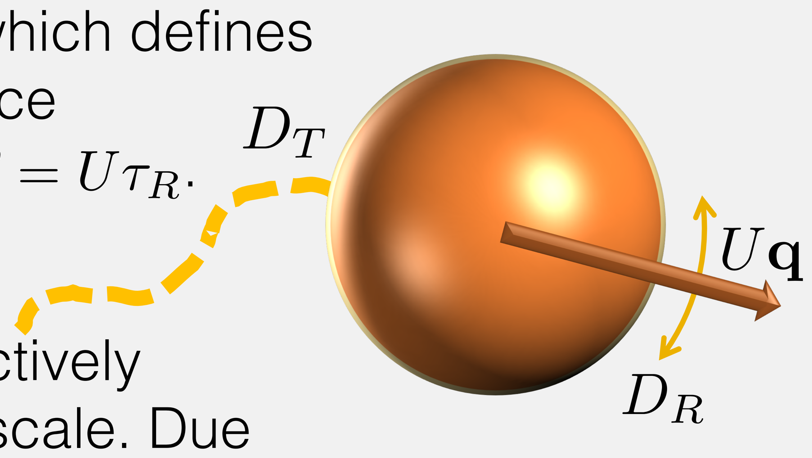
Case 1. Infinite Suspension

Case 2. Bounded by Walls

Model and Theory

Active Brownian Particles (ABPs)

Microswimmers are modeled as ABPs. In addition to the Brownian motion with translational diffusivity D_T, an ABP self-propels with swim speed U into direction q which reorients with rotational diffusivity D_R, which defines the reorientation time $\tau_R = 1/D_R$. The persistence length of swimming motion is called run length $\ell = U\tau_R$.

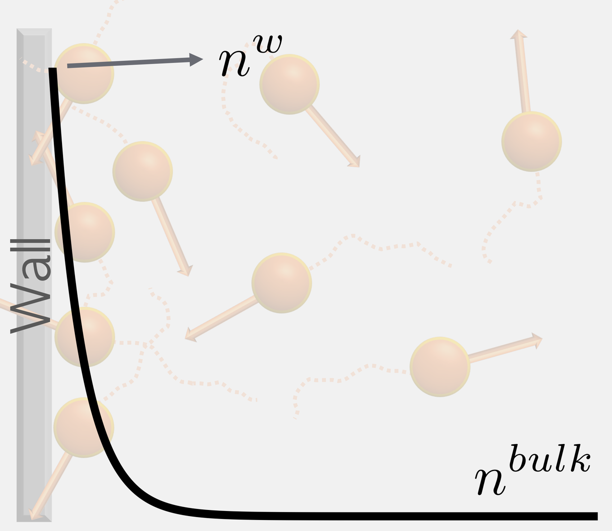


The Swim Pressure

Swimming motion with random orientations effectively increases translational diffusivity at a long time scale. Due to the enhancement of diffusivity, ABPs exert extra pressure, the swim pressure compared to their passive Brownian analogs.

Link to reference: Takatori and Brady, *PRL* (2014)

Concentration of ABPs, n



Effective Diffusivity

$$D_{eff} = D_T + D_{swim} \quad \left(D_{swim} \sim \frac{\ell^2}{\tau_R} \right)$$

Pressure Exerted by ABPs on the Wall

Link to reference: Yan and Brady, *JFM* (2015)

$$\Pi^w = n^w k_B T = \left[n^{bulk} \left(1 + \frac{D_{swim}}{D_T} \right) \right] k_B T$$

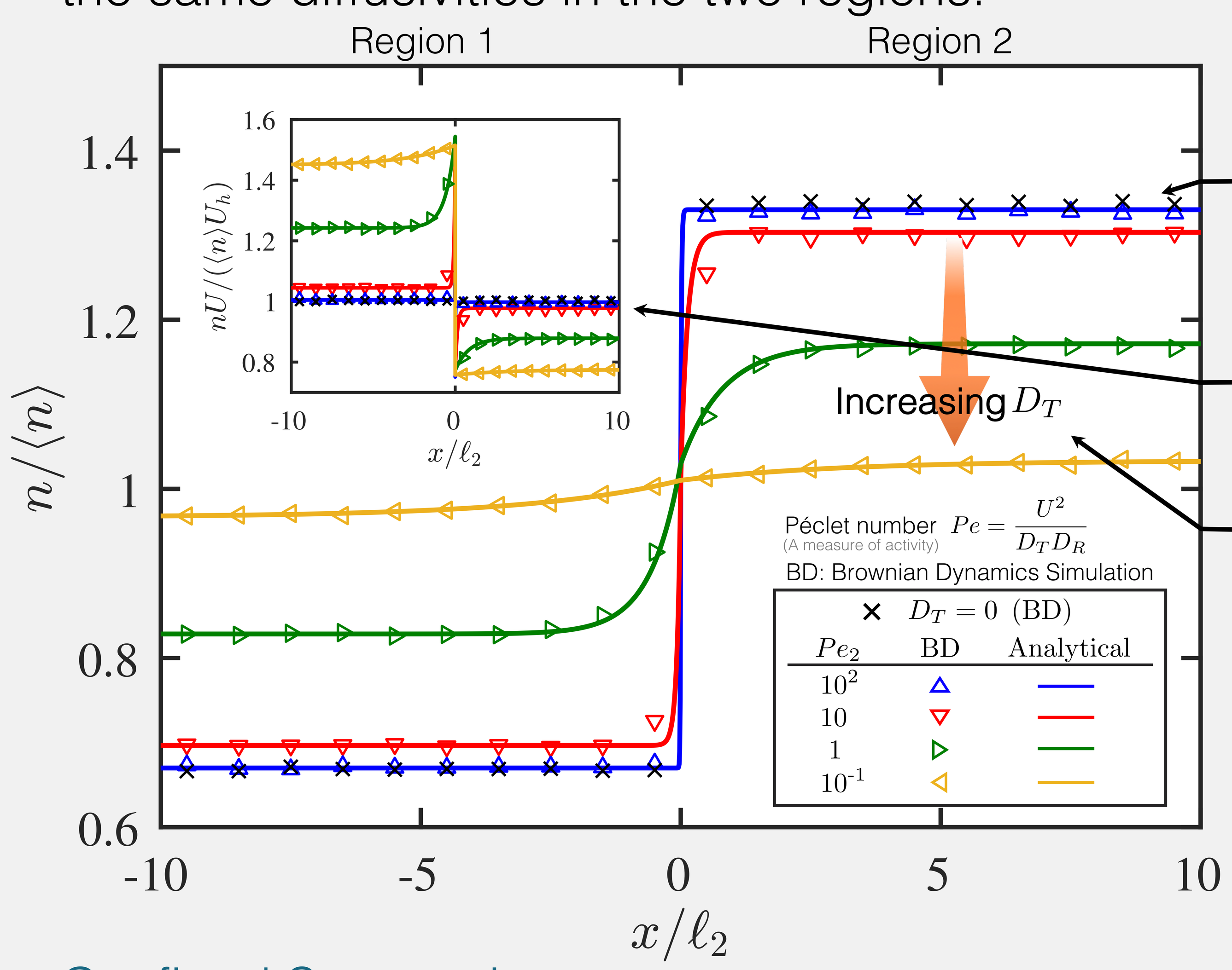
$$= n^{bulk} k_B T + \Pi^{swim}$$

Results and Conclusions

Infinite Suspension:

Concentration Is Governed by Swim Speed and Modulated by Diffusivities

Concentration of ABPs swimming twice faster in region 1 (left; $x<0$) but with the same diffusivities in the two regions:



It can be analytically shown that $nU = \text{const.}$ in the singular athermal (purely active; $D_T = 0$) limit.

Highly active ($Pe \gg 1$) particles also have $nU \approx \text{constant}$.

Jump in concentration smeared out as the product of diffusivities $D_R D_T$ increases.

Confined Suspension:

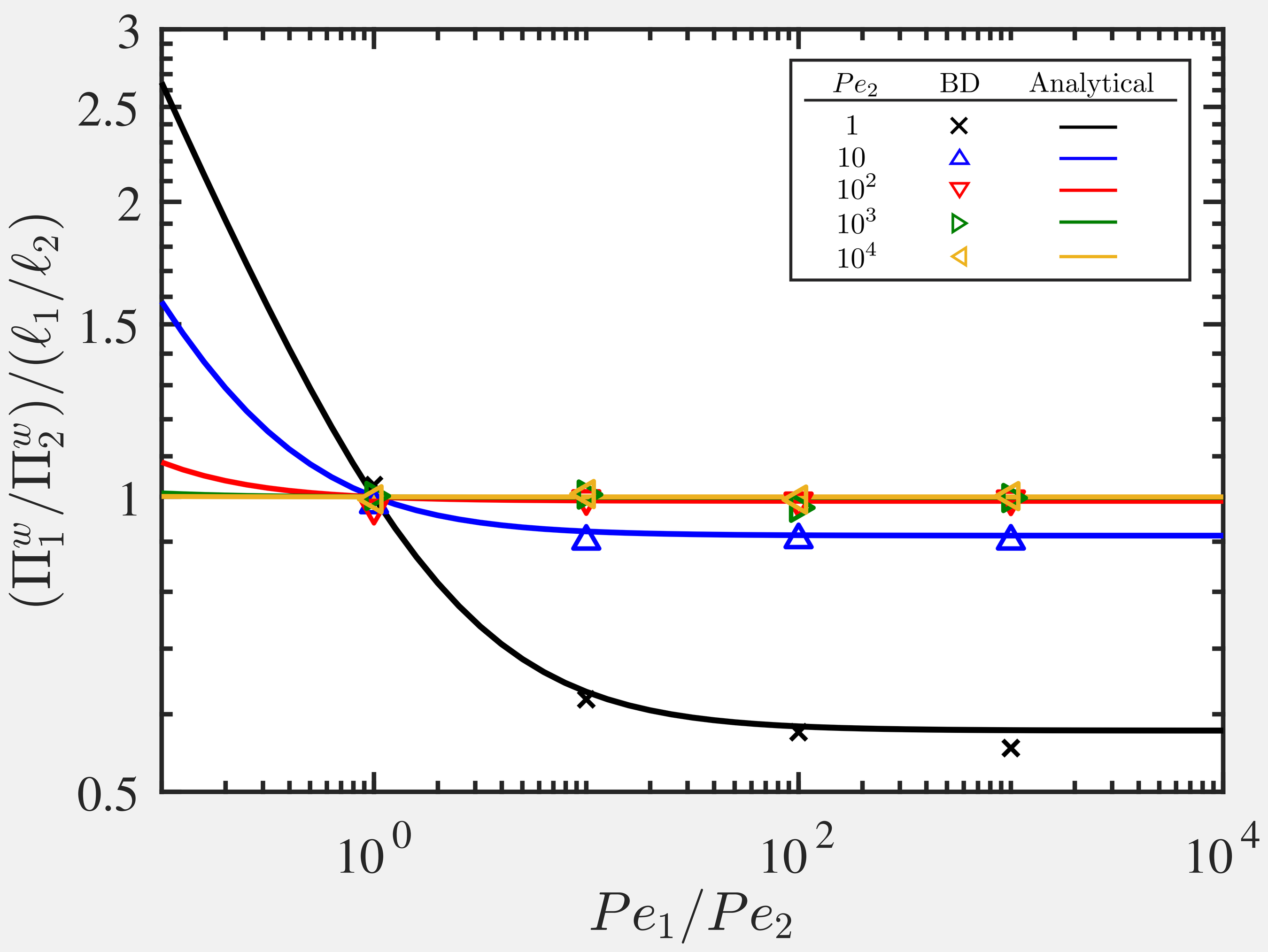
Pressure Exerted by Highly Active Particles Is Linear with Their Run Length

For highly active particles, $D_{swim} \gg D_T$, which leads to

$$\Pi^w \approx \Pi^{swim} = n^{bulk} \left(\frac{k_B T}{D_T} \right) D^{swim} \approx \zeta n^{bulk} U \ell \propto \ell$$

ζ : Hydrodynamic drag coefficient (Stokes-Einstein-Sutherland Relation)

$n^{bulk}U$: Nearly constant for highly active particles



If $U_1 > U_2$ and $D_{R1} = D_{R2}$,

$n^{bulk}U \approx \text{const.} \Rightarrow n_1^{bulk} < n_2^{bulk}$

$\Pi^w \propto \ell \Rightarrow \Pi_1^w > \Pi_2^w$

For global mechanical balance, the total pressure including fluid pressure must be constant.

$$\Pi^w + p_f^w = \text{const.}$$

Consequently,

$$n_1^{bulk} < n_2^{bulk} \quad \text{yet} \quad p_{f1}^w < p_{f2}^w$$

Fluid pressure is lower in dilute region. Thus, fluid can flow from concentrated to dilute region: **reverse osmotic effect**!!

* hrow@caltech.edu

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G3, Co-advised by Prof. John F. Brady and Prof. Zhen-Gang Wang

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