# Dynamical systems prespective of cell separation using dielectrophoresis

ESM-6984: Frontiers in dynamical systems
Engineering Science and Mechanics,Virginia Tech

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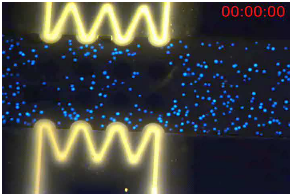


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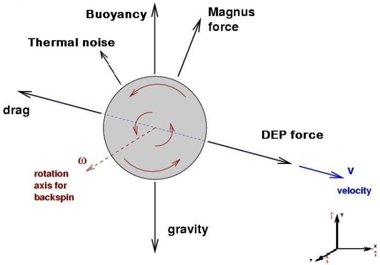
# What is Dielectrophoresis and why?

- Dielectrophoresis(DEP) is the motion of a particle due to the interaction between a non-uniform electric field and its induced dipole moment in the particle.
- Established technique to discriminate between distinct cellular identities in heterogeneous populations
    - Identify tumor stem cells
    - Isolate stem cells in adipose tissue
- Cell manipulation for drug targeting and lab on chip concept for safer and confident clinical trials.
- Common methods like flow cytometry, magnetic bead-coupled cell separation depend on specific cell-surface antigens

# Modeling forces

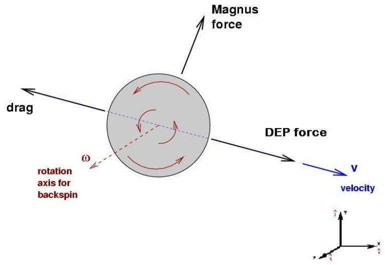
- Dielectrophoresis
  - Translational force
  - Electro-rotation Torque
- Drag force
  - Drag force
  - Rotational friction
- Gravitational force
- Buoyancy
- Magnus force
- Inertial force
- Thermal noise




- **Characteristic numbers**
  - Cell dim.: 1-10 $\mu m$
  - Domain dim.: 100-500 $\mu m$
  - Typical velocity: $< 100 \mu m s^{-1}$
  - Knudsen $< 0.1$
  - Reynolds $<< 1$

# Modeling forces

- **Dielectrophoresis**
  - **Translational force✓**
  - **Electro-rotation Torque?**
- **Viscous force**
  - **Drag force✓**
  - **Rotational friction?**
- Gravitational force✓
- Buoyancy✓
- **Magnus force?**
- **Inertial force?**
- Thermal noise

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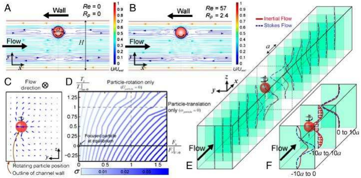
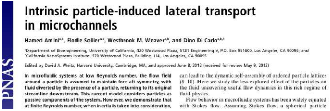
# Relevant questions for dynamical systems

- Role of inertial effects of the particle on the flow and the resulting transport
- Can we explain cell's preferential motion using electro-rotation?




(a)



PNAS

Intrinsic particle-induced lateral transport in microchannels

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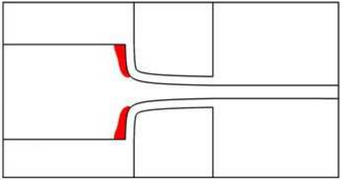
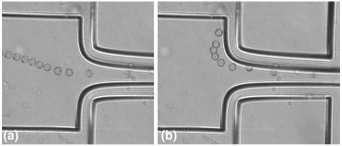
In microfluidic systems at low Reynolds number, the flow field around a particle is assumed to maintain fore-aft symmetry, with fluid diverted by the presence of a particle, returning to its original streamline downstream. This current model considers particles as passive components of the system. However, we demonstrate that at finite Reynolds number, when inertia is taken into consideration, can lead to the dynamic self-assembly of ordered particle lattices (8–10). Here we study the less explored effect of the particles on the fluid uncovering useful flow dynamics in this rich regime of fluid physics.

Flow behavior in microfluidic systems has been widely equated with Stokes flow. Assuming Stokes flow, a spherical particle

(b)





# Fluid forces

- **Drag force** is given by Stokes Law:

$$\mathbf{F}_d = -6\pi\eta a(\mathbf{u}_p - \mathbf{u}_f)$$

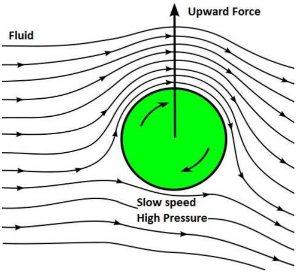
- **Magnus force**:

$$\mathbf{F}_M = \frac{C_L \nu}{r\omega} \frac{\pi d^3}{16} \rho_f \left[\vec{\omega} x(\vec{u}_p - \vec{u}_f)\right]$$

$$C_L = 0.45 + \left(2\frac{r\omega}{\nu} - 0.45\right) \exp\left(-0.075\frac{r\omega}{\nu}^{0.4} Re^{0.7}\right), Re < 140$$

- **Rotational friction**:

$$\mathbf{T}_f = -8\pi\eta a^3 \omega_o$$



# Force and torque due to dielectrophoresis

- Dielectrophoresis force attracts or repells particles from region of high electric fields :

$$\mathbf{F}_{DEP}(\vec{r}_0, t) = 2\pi\epsilon_f a^3 \frac{\epsilon_p^* - \epsilon_f^*}{\epsilon_p^* + 2\epsilon_f^*} \vec{\nabla}[\vec{E}^2(\vec{r}_0, t)]$$

  - $\vec{E}$ is inhomogeneous and hence gradient is non-zero.
- For oscillating electric-fields, time-averaged form for the translational force:

$$\langle \mathbf{F}_{DEP} \rangle = 2\pi\epsilon_f a^3 Re\left[\frac{\epsilon_p^* - \epsilon_f^*}{\epsilon_p^* + 2\epsilon_f^*}\right] \vec{\nabla}[\vec{E}_{rms}^2(\vec{r}_0)]$$

- Time-averaged form for the electro-rotational torque:

$$\langle \mathbf{\Gamma}_{DEP} \rangle = -4\pi\epsilon_f a^3 Im\left[\frac{\epsilon_p^* - \epsilon_f^*}{\epsilon_p^* + 2\epsilon_f^*}\right] \vec{E}_{rms}^2(\vec{r}_0)$$

where, Complex dielectric constant: $\epsilon^* = \epsilon + \frac{\sigma}{j\omega}$ and complex Clausius-Mossitti factor: $K(\omega) = \frac{\epsilon_p^* - \epsilon_f^*}{\epsilon_p^* + 2\epsilon_f^*}$

# Future work

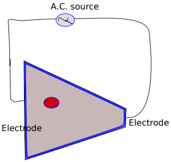
- Translation of the particle:

$$m\frac{d\vec{u}}{dt} = \mathbf{F}_d + \mathbf{F}_M + \mathbf{F}_{DEP}$$

- Rotation of the particle:

$$I\frac{d\vec{\omega}}{dt} = \mathbf{T}_f + \mathbf{\Gamma}_{DEP}$$

- Develop electric potential for a simple electrode configuration with pressure driven flow:




- Use the system equations to perform scaling analysis of the Magnus effect, translational DEP force and DEP moment and perform stability analysis.

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