Electro-Guided Self-Propelled Ionic Liquid Droplets as Vessels for Chemical Reactions

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Chemotaxis

• Movement of an organism in response to a chemical stimulus

• Certain single and multicellular organisms have this ability

• Bacteria, Viruses and even some somatic cells i.e white blood cells

• Chemoattractant: food source

• Chemorepellent: toxin
Synthetic Systems

• Development of synthetic biomimetic “vehicles”

• These “vehicles” move in response to external stimuli

• Developing smart droplets

• Designed to move across the liquid/air interface

• Applications include micro-vehicles for chemical reactions, cargo transport to desired destinations, dynamic sensing, leak detection and drug delivery
Introduction

• “Vehicle” movement has been achieved through the use of surfactant molecules

• Classical example is propelling a paper boat by applying a small amount of liquid soap to the end
Surfactants

- Long chained molecules
- Charged hydrophilic “head”
- Hydrophobic “tails”
- Surface active
- Alter surface tension
Surface Tension

- Contractile layer
- Surface molecules experience greater attraction to neighbours compared to bulk molecules
- Liquid flows from low to high surface tension
- Marangoni effect
Ionic liquids

- Negligible vapour pressure
- High thermal stability
- High ionic conductivity
- Excellent solvents
- “Designer” solvents

\[ \text{P}^{+} \quad \text{Cl}^{-} \quad \text{Br}^{-} \]
Droplet Composition

$[P_{6,6,6,14}][\text{Cl}]$ Droplet

Low Cl$^-$ concentration

High Cl$^-$ concentration

$\text{Cl}^-$
Droplet Movement

A

1 mm

2 mm

HCl

B

Direction of motion

Low $\gamma$

High $\gamma$

Cl$^-$

[PF$_{6}$]$	extsuperscript{+}$

C

Direction of motion

Low $\gamma$

High $\gamma$

D

Low $\gamma$

High $\gamma$

Low Cl$^-$ concentration

High Cl$^-$ concentration
Chemotactic Droplet Example

Speed x 4
Chemotactic Droplets

- Droplets follow a Cl⁻ gradient to desired destinations
- Many methods for generation of gradients
- Droplet solely composed of IL
- Multiple droplets can be moved to destination
- Merging of droplets possible
- Chemical gradients will quickly come to equilibrium
- Droplet can only be moved to a single destination
Electrotactic Droplets

- On demand generation of gradients at the electrodes
- Salt solutions used as electrolyte
- Control over length of gradients
- Reversible droplet movement
- Allows for droplet to be moved to several destinations
Droplet Movement

Cathode | Anode
---|---

A

B
Low $\gamma$

C
Low $\gamma$

D
Low $\gamma$

- $|$ +
- $|$ +
- $|$ +

Low Cl$^-$ concentration at cathode

NaCl $10^{-2}$ M

High Cl$^-$ concentration at anode
$10^{-3}$ M NaCl used as electrolyte, 9 V applied across the solution.
Chip Design

- Chips 3D printed
- Electrodes - Realizer SLM-50 3D printer
- Channels - Objet350 Connex
- Electrodes embedded within the channels
Example of Electrotactic Ionic liquids

NaCl $10^{-3}$ M, 9 V, Speed x 5
Electro-Generated Gradients

- Fluorescent dye: lucigenin
- Strongly quenched by Cl⁻
- 369 nm LED source

10⁻³ M NaCl
10⁻⁴ M lucigenin
Can be reversed
Adding Functionality

- Have droplets perform more sophisticated tasks
- Micro-vessels for chemical reactions
- Cargo transport to desired destinations
- Dynamic sensing units
- Leak detection
Chemical Reactions: Metal ion sensing

- Reactions take place inside droplet
- Predetermined locations
- Analytes: Co\(^{2+}\) and Cu\(^{2+}\)
- Metal ion sensing dye: PADAP
Future Work

• Develop and optimise reactions within the droplets

• Novel tasks for droplets

• Developing new types of droplets (different Ionic liquids)

• Using other types of micro vehicles
Conclusion

• Chemo and electro tactic droplets

• Chemotactic: energy free autonomous movement

• Electrotactic: long lived chemical gradients, reversible movement to multiple destinations

• Vessels for chemical reactions

• Transport cargo to desired destinations
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