



Introduction to Micro/Nanofluidics

Lecture 2

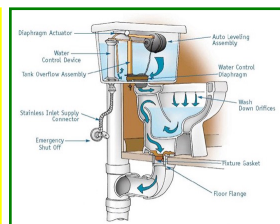
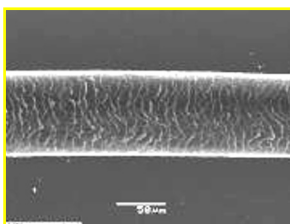
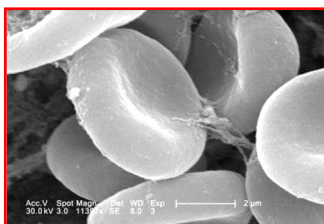
Dr. Yi-Chung Tung

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What is Microfluidics

- **Microfluidics** = Micro + Fluidics
- **Micro/Nano:** 10^{-6} , 10^{-9}
 - Small size (sub-mm)
 - Small volumes (μl , nl, pl)
- **Fluidics:** handling of liquids and/or gases



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Advantages of Microfluidics

- The motivation for using a microfluidic system is analogous to the argument for using integrated circuits (IC) to replace the discrete component circuits.
- Advantages:

Miniaturization: Portability (Lab-on-a-Chip)

Integration: Low Costs, Batch Fabrication

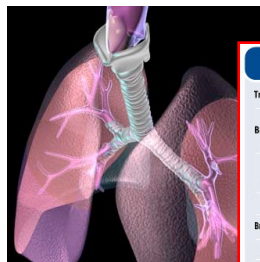
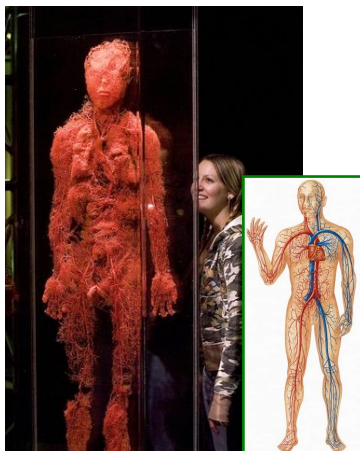
Automation: Simplicity of Operation

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Microfluidics *in vivo*

- Circulating and Respiratory System



Location	Generation
Trachea	0
Bronchi	1
Bronchioles	2, 3, 4, 5
Terminal bronchioles	16
Respiratory bronchioles	17, 18, 19
Alveolar ducts	T, 20, T, 21
Alveolar sacs	T, 22, T 23

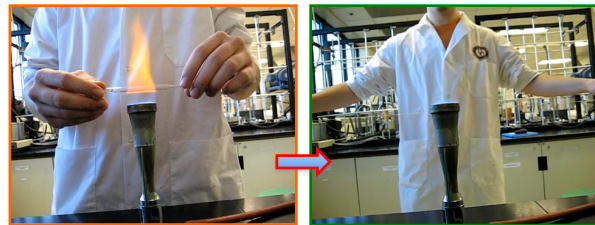
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Old School Microfluidics

- Historical Microfluidics: Glass capillary
- Glass Capillary has been broadly exploited in labs
- Capillary Electrophoresis (CE)

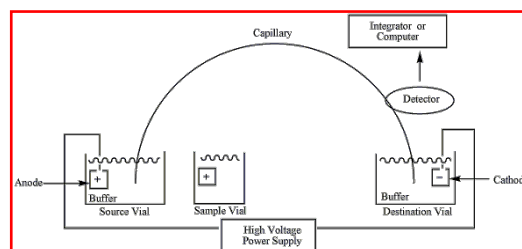
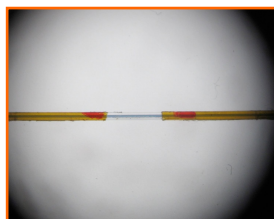


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Capillary Electrophoresis (CE)

- Introduced in the 1960s, the technique of capillary electrophoresis (CE) was designed to separate species based on their size to charge ratio in the interior of a small capillary filled with an electrolyte.

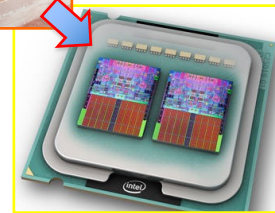
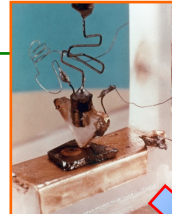
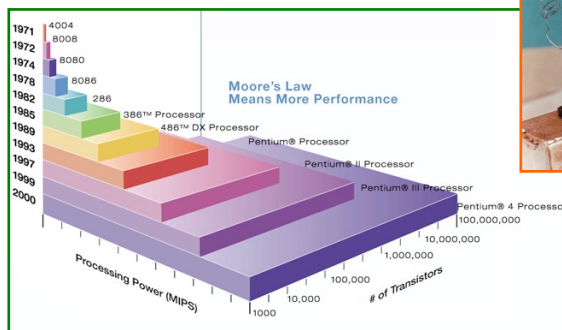


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New Era of Microfluidics

- Due to the advancement of micro/nano fabrication technology, “microfluidics” has been redefined.

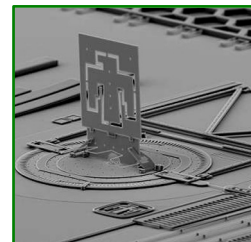
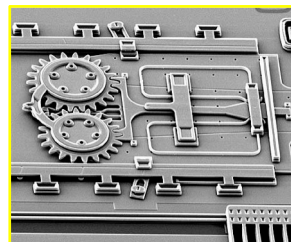
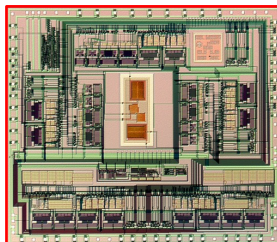


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Microelectromechanical Systems

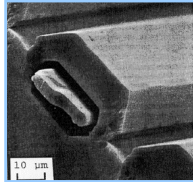
- Microelectromechanical Systems (MEMS).
- MEMS is the integration of *mechanical elements, sensors, actuators, and electronics* on a common silicon substrate through microfabrication technology.



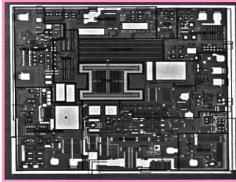
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Advancement of MEMS

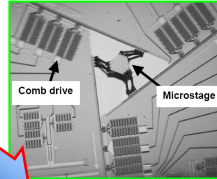


Ikeda et al. 1990 (Japan)

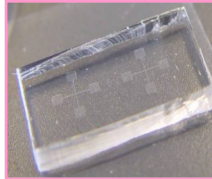


Analog Device ADXL50

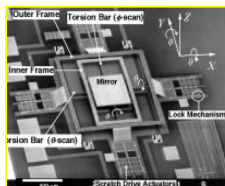
Polymer



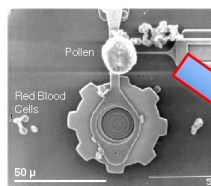
Walraven et al., 2003 (Sandia)



www.uni-ulm.de

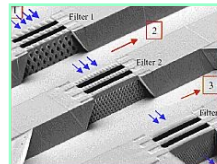


Toshiyoshi et al., 1998 (UCLA)

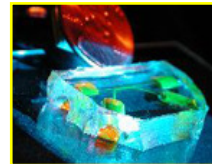


mems.andia.gov

Silicon-Based



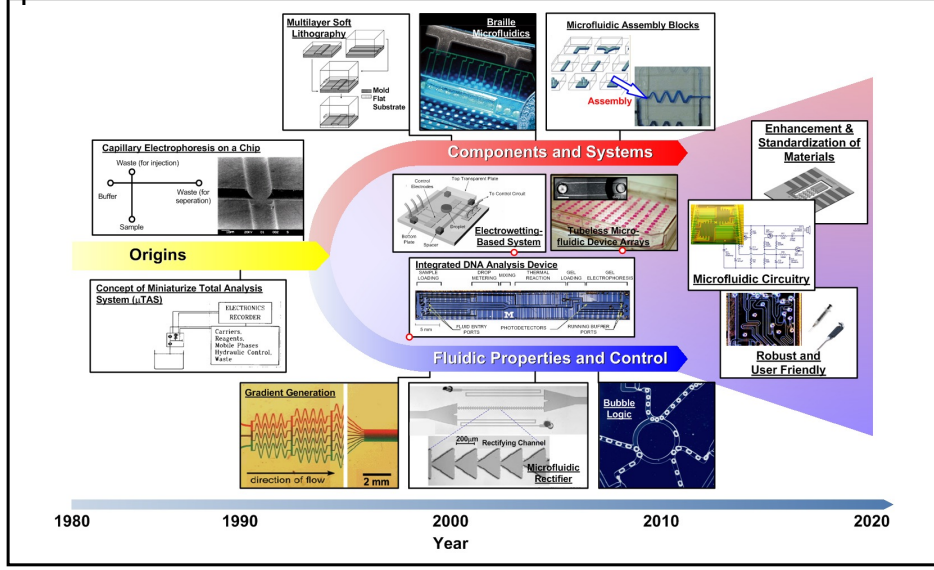
www.mic.dtu.dk



Takayama et al, 2003 (UM)

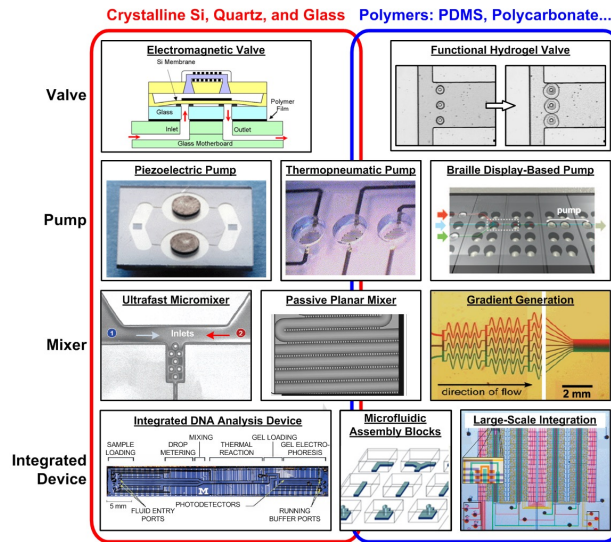


Development of Microfluidics





Materials of Microfluidic Devices



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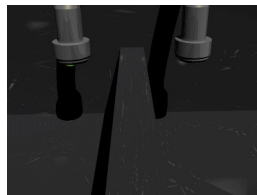


Fluid Mechanics

- **Density (ρ):**
Density = Mass/Volume (kg/m^3)
- **Dynamic Viscosity (Viscosity, μ):**
Viscosity is a measure of the resistance of a fluid which is being deformed by either shear stress or tensional stress.

Temp ($^{\circ}\text{C}$)	Density (kg/m^3)
100	958.4
80	971.8
60	983.2
40	992.2
30	995.6502
25	997.0479
22	997.7735
20	998.2071
15	999.1026
10	999.7026
4	999.9720
0	999.8395
-10	998.117
-20	993.547
-30	983.854

The density of water in kilograms per cubic meter (SI unit) at various temperatures in degrees Celsius.
The values below 0°C refer to supercooled water.



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Fluid Mechanics

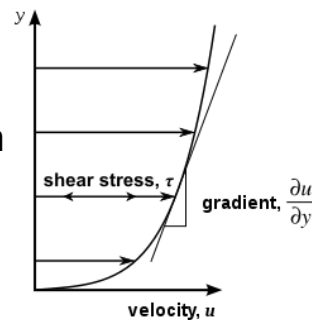
- **Viscosity (μ) – Newton's Theory:**

$$\tau = \mu \frac{du}{dy}$$

where τ is Fluid Shear Stress
where (du/dy) is change of fluid velocity in y direction

- This is a constitutive equation (a reasonable first approximation).

- **Newtonian Fluids.**



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Fluid Mechanics

- **Viscosity (μ):**

- Unit: $\text{kg}/(\text{m}\cdot\text{s}) = \text{Pa}\cdot\text{s} = 10 \text{ Poise}$
- Viscosity of Water at 20°C
= 0.01002 Poise
= 1.002 cP (centipoise)
= $1.002 \text{ mPa}\cdot\text{s}$
- Viscosity of SAE 30 oil at 20°C
= 2.9 Poise

Temperature [$^\circ\text{C}$]	Viscosity [$\text{mPa}\cdot\text{s}$]
10	1.308
20	1.002
30	0.7978
40	0.6531
50	0.5471
60	0.4668
70	0.4044
80	0.3550
90	0.3150
100	0.2822

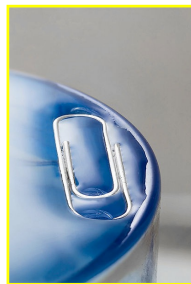
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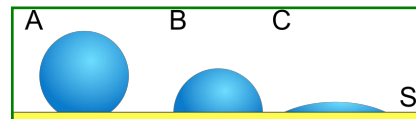
Fluid Mechanics

- **Surface Tension (γ):**

Surface tension is a property of the surface of a liquid. Surface tension is caused by cohesion (the attraction of molecules to like molecules).



Hydrophobic -> Hydrophilic



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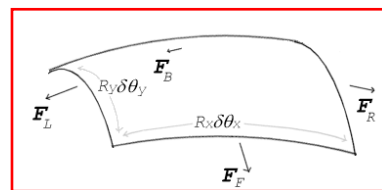


Fluid Mechanics

- **Surface Tension (γ):**

Young-Laplace Equation:

$$\Delta p = \gamma \left(\frac{1}{R_x} + \frac{1}{R_y} \right)$$



Where Δp is the pressure difference, γ is surface tension, R_x and R_y are radii of curvature in each of the axes that are parallel to the surface.

Water at 25°C, $\gamma = 71.97$ (dyn/cm)

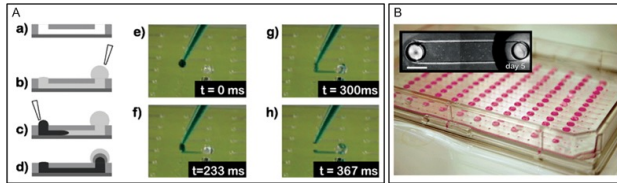
Δp for water drops of different radii at STP				
Droplet radius	1 mm	0.1 mm	1 μm	10 nm
Δp (atm)	0.0014	0.0144	1.436	143.6

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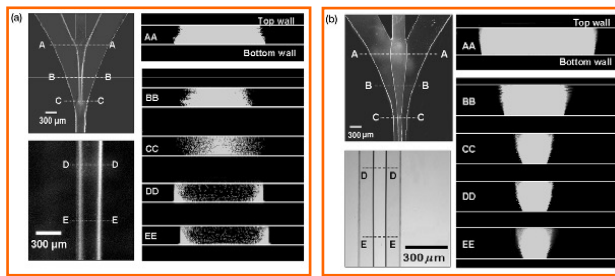
Fluid Mechanics

- Utilize Surface Tension in Microfluidics



Surface Tension Driven Flow

Air-Liquid Two Phase Flow



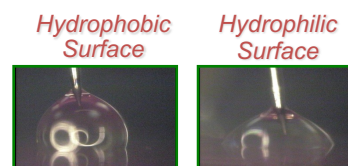
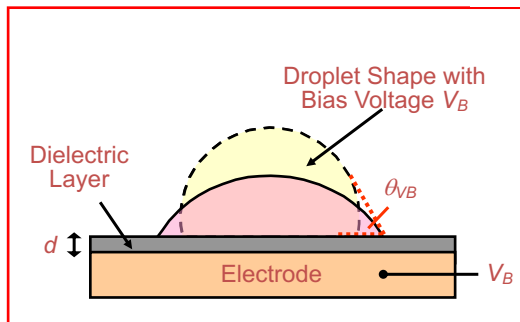
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Fluid Mechanics

- Control Surface Tension in Microfluidics: Electro-Wetting

$$\cos \theta_v = \cos \theta_o + \frac{1}{2} \frac{\epsilon \epsilon_o}{\gamma_{LV} t} V^2$$

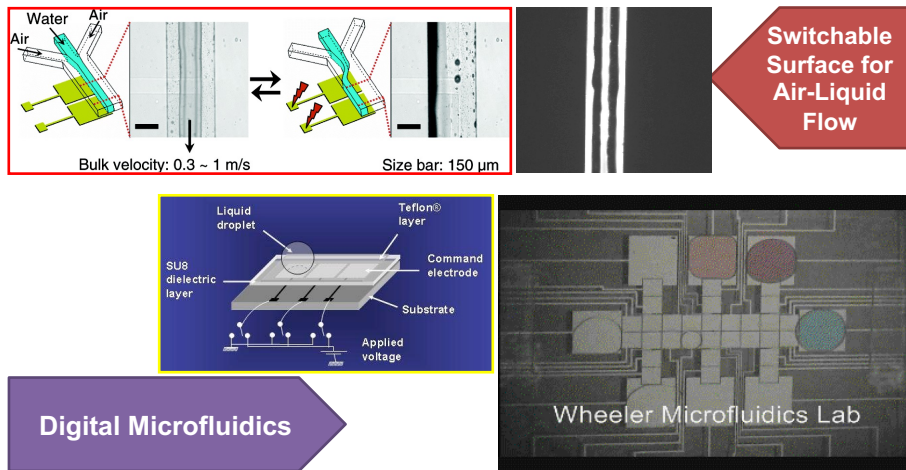


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Fluid Mechanics

- **Electro-Wetting Microfluidics**



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Fluid Mechanics

- **Reynolds Number (Re):**

Re is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces.

$$Re = \frac{\rho VL}{\mu}$$

V is the mean fluid velocity (m/s)

L is the a characteristic linear dimension (m)
(traveled length of fluid or hydraulic diameter etc.)

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Fluid Mechanics

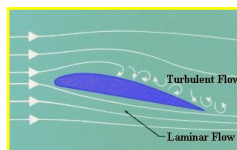
- **Reynolds Number (Re):**
 - Large Re means inertial force dominates:
Turbulent Flow (unsteady flow stream, i.e. swirls and vortices).
 - Small Re means viscosity force dominates:
Laminar Flow (fluid stream follows regular paths, i.e. streamlines).
 - For flow in a pipe, laminar flow occurs when $Re < 2300$, and turbulent flow occurs when $Re > 4000$.
 - In the interval between 2300 and 4000:
Transition Flow.

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Fluid Mechanics

- **Laminar Flow vs. Turbulent Flow**
 - Blood Flow in brain $\sim 1 \times 10^2$
 - Blood flow in aorta $\sim 1 \times 10^3$
 - Typical pitch in Major League Baseball $\sim 2 \times 10^5$
 - Person swimming $\sim 4 \times 10^6$



Low Speed
Laminar
small Re

High Speed
Turbulent
high Re

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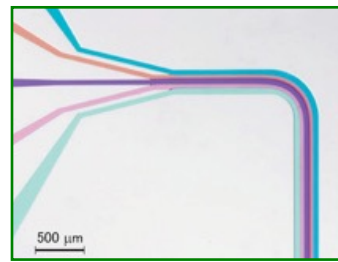
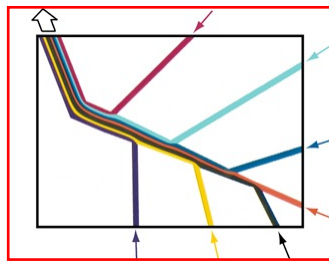
Fluid Mechanics

- Microfluidics (Laminar or Turbulent?)

$$Re = \frac{\rho VL}{\mu}$$

For example: $V = 1$ (mm/s), $L = 100 \mu\text{m}$

$$Re = \frac{\rho VL}{\mu} = \frac{1000(\text{kg}/\text{m}^3) \times 10^{-3}(\text{m}/\text{s}) \times 100 \cdot 10^{-6}(\text{m})}{0.001(\text{kg}/\text{m} \cdot \text{s})} = 0.1$$



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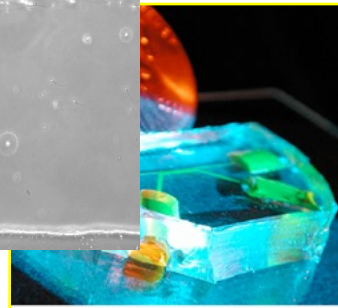
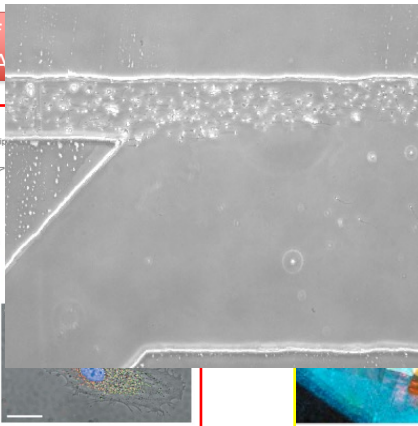
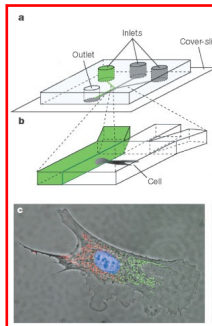


Fluid Mechanics

- Laminar Flow in Microfluidic Channel

Partial Treatment of
Flows (PA

Term Sorter
ar vs. Diffusion)



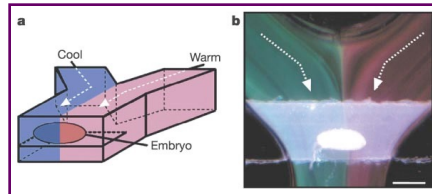
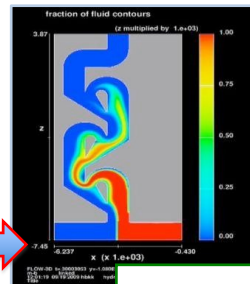
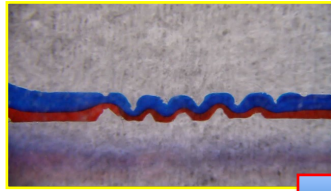
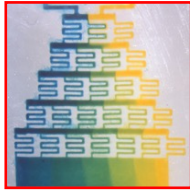
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Fluid Mechanics

- Limits in Microfluidic Channel

Gradients Generation – Difficult to Mix



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Fluid Mechanics

- **Reynolds Number (Re):**

The ratio of inertial forces to viscous forces.

$$Re = \frac{\rho VL}{\mu}$$

- **Weber Number (We):**

The ratio of inertia forces to surface tension forces.

$$We = \frac{\rho V^2 L}{\sigma}$$

- **Bond Number (Bo):**

The ratio of body forces to surface tension forces.

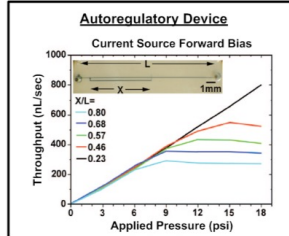
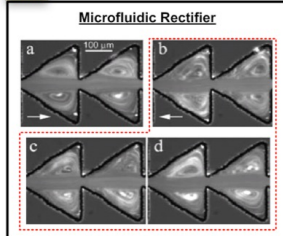
$$Bo = \frac{\rho a L^2}{\gamma}$$

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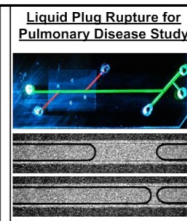
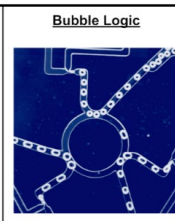
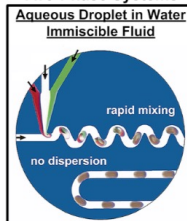


Other Microfluidic Devices

Complex Fluids



Two-Phase Systems

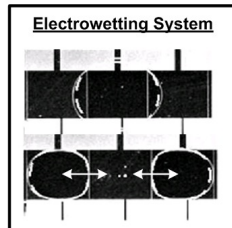


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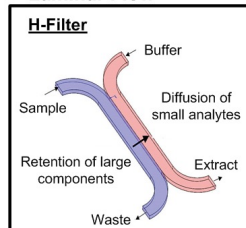


Conclusion

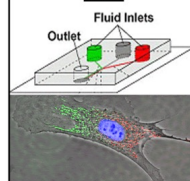
Surface Tension



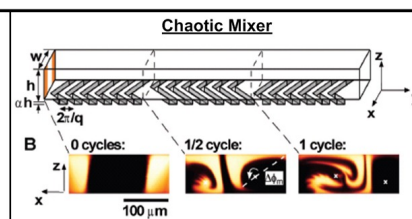
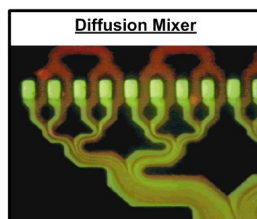
Laminar Flow



Partial Treatment of Cells



Diffusion vs. Convection



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Conclusion

- Advantages and Limitations of Microfluidics
- Challenges
- Future Directions

