Building College-University Partnerships for Nanotechnology Workforce Development

# Microfluidics, A Review with Selected Biological Applications

## PART 1


© 2018 The Pennsylvania State University

# Outline

- Microfluidics Overview
- Physics of Microfluidics
- Operational Components
- Materials and Applications

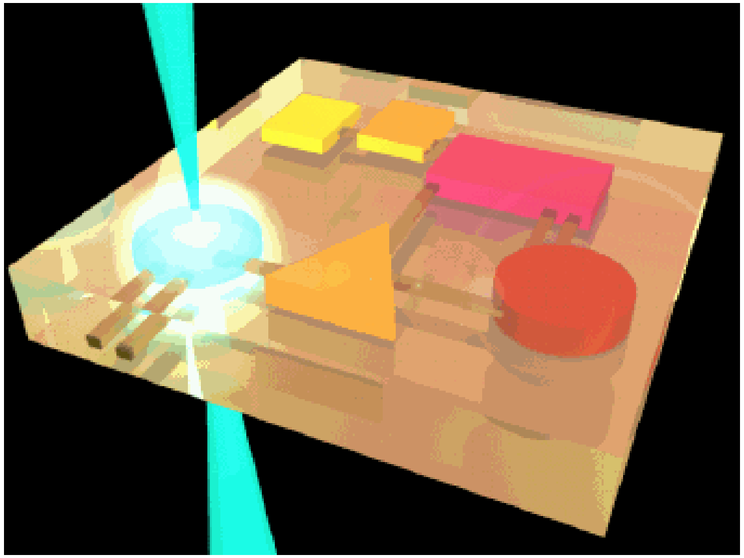

© 2018 The Pennsylvania State University

# Microfluidics Overview

Microfluidics is the science of designing, manufacturing, and formulating devices and processes that process and handle volumes of fluid on the order of Nano ($10^{-9}$) or Pico ($10^{-12}$) liters.

Liquids in nanoliters

30 nL = 1/1000$^{th}$ of 1 droplet




© 2018 The Pennsylvania State University

# Microfluidics Overview

- Microfluidic devices handle small amounts of fluid.  Good when only small amounts are available, or good for conservation
- Generally use small amounts of energy
- Sealed system so contamination is well controlled
- Small size leads to mobility, no lab needed
- Reaction can be fast


© 2018 The Pennsylvania State University

# Microfluidics Overview

Microfluidics is a multidisciplinary field intersecting engineering, physics, chemistry, biochemistry, nanotechnology, and biotechnology, with practical applications to the design of systems in which small volumes of fluids will be handled

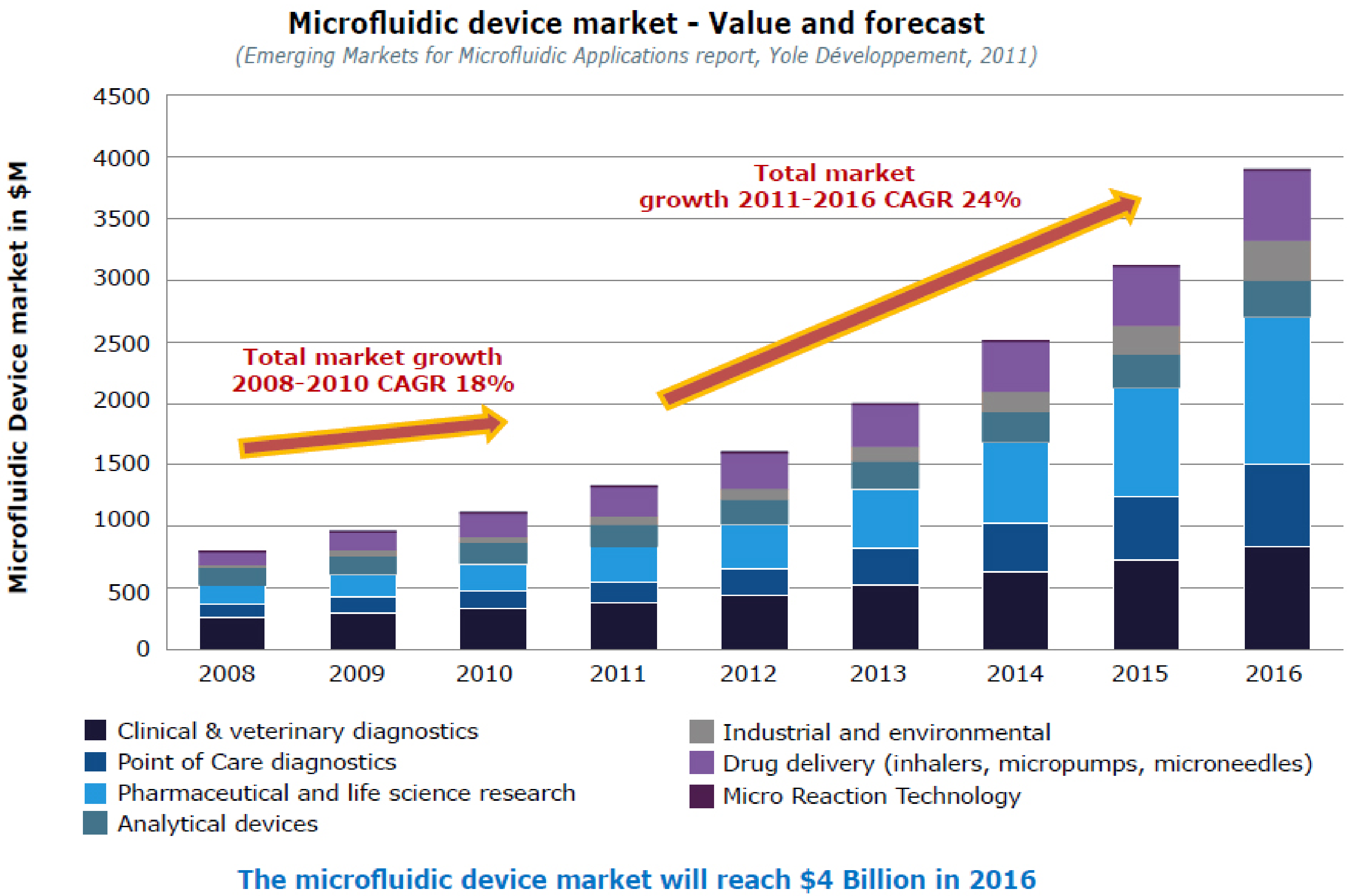
- small volumes (µL, nL, pL, fL)
- small size
- low energy consumption
- effects of the micro domain

Typically fluids are moved, mixed, separated or otherwise processed. Numerous applications employ passive fluid control techniques like capillary forces

http://en.wikipedia.org/wiki/Microfluidics


© 2018 The Pennsylvania State University

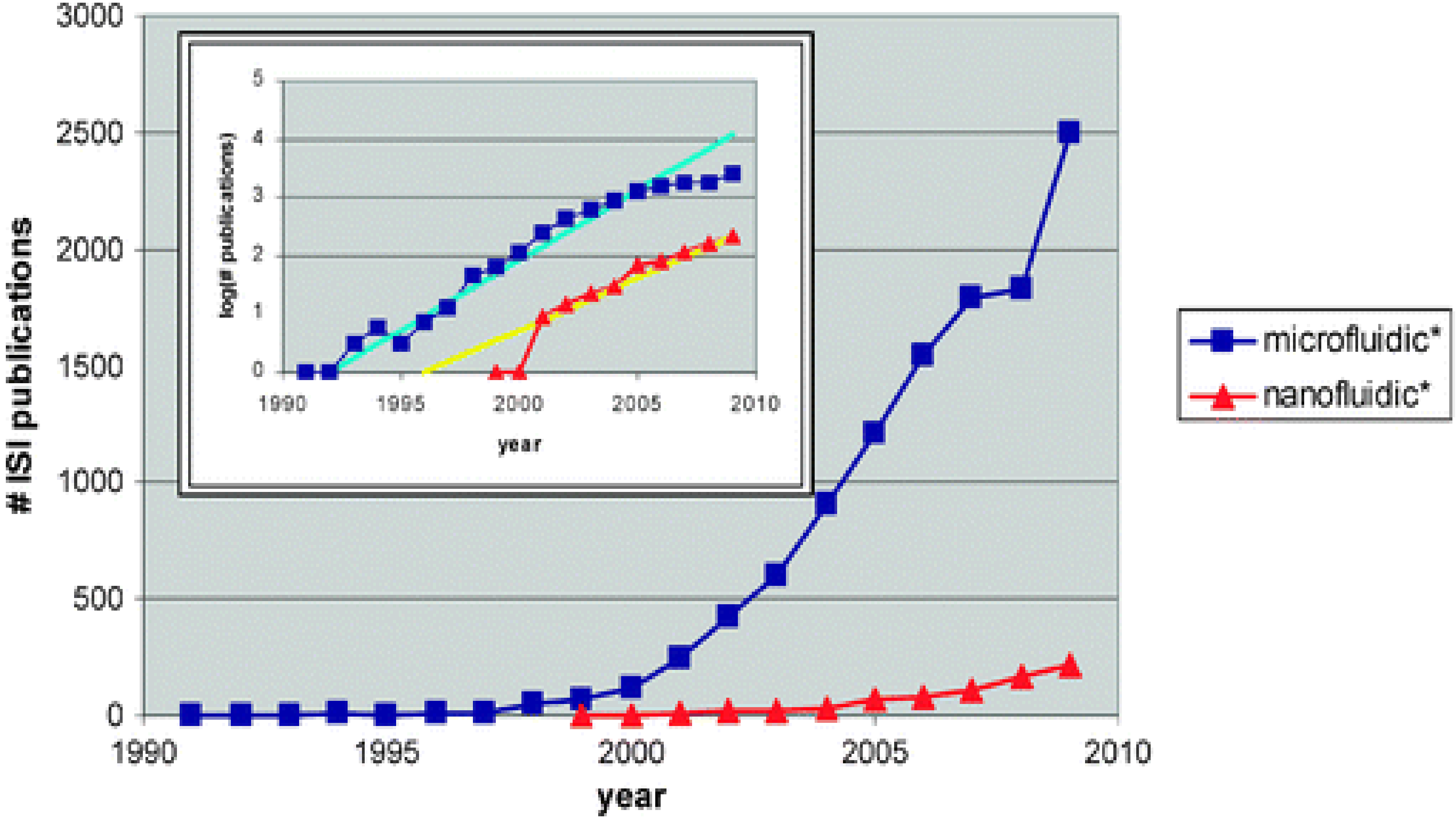
# Growth of Microarrays




Contributed by Frédéric Breussin, Business Unit Manager
Microfluidics & Medical Technologies, Yole Développement


© 2018 The Pennsylvania State University

# Growth of number of ISI publications found with microfluidic and nanofluidic over the past 20 years




**Chemical Society Reviews**
**From microfluidic applications to nanofluidic phenomena**
**Albert van den Berg ,Harold G. Craighead and Peidong Yang**


© 2018 The Pennsylvania State University

# Outline

- What is Microfluidics
- Physics of Microfluidics
  - Flow
  - Renyolds Number
  - Peclet Number
- Operational Components
- Materials and Applications


© 2018 The Pennsylvania State University

# Physics of Microfluidics

- The small scale of microfluidics leads to unique conditions and considerations
- Factors like surface tension, unique flow characteristics, air traps, and many other factors contribute to the complexity of microfluidics.
- We will briefly examine selected factors
  - Flow
  - Mixing


© 2018 The Pennsylvania State University

# Physics of Microfluidics

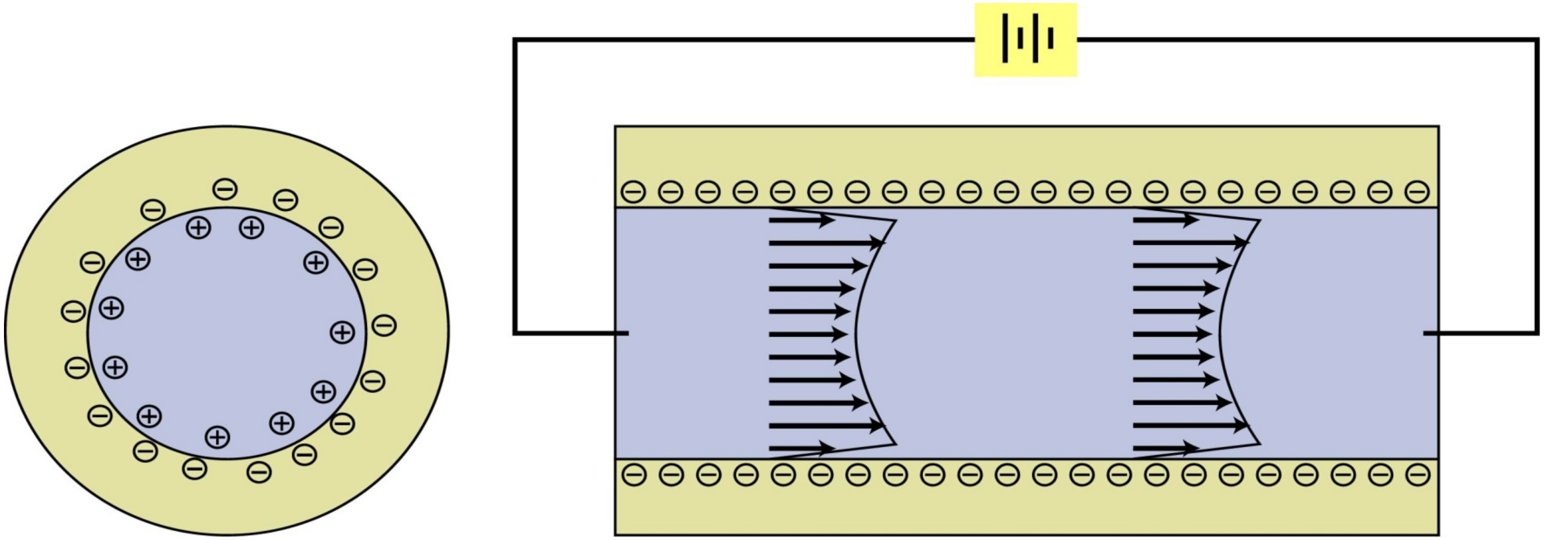
Electrokinetic effects, general term to describe the movement of ions in a fluid that is subjected to an electric potential.

- Two major types of flow types, electroosmosis, or electrophoesis
- Electroosmosis, sidewall driven
- Electrophroesis, particle flow


© 2018 The Pennsylvania State University

# Electroosmosis

- If the walls of a channel have an electric charge (-) ions in the fluid with an opposite charge (+) will be attracted to the walls.
- A layer of immobile ions forms at the channel surface while a layer of mobile ions forms at the fluid side (electric double layer).
- When an electrical potential is applied to the channel the ions in the fluid will be attracted to the opposite pole
- These ions will drag along the remaining fluid.



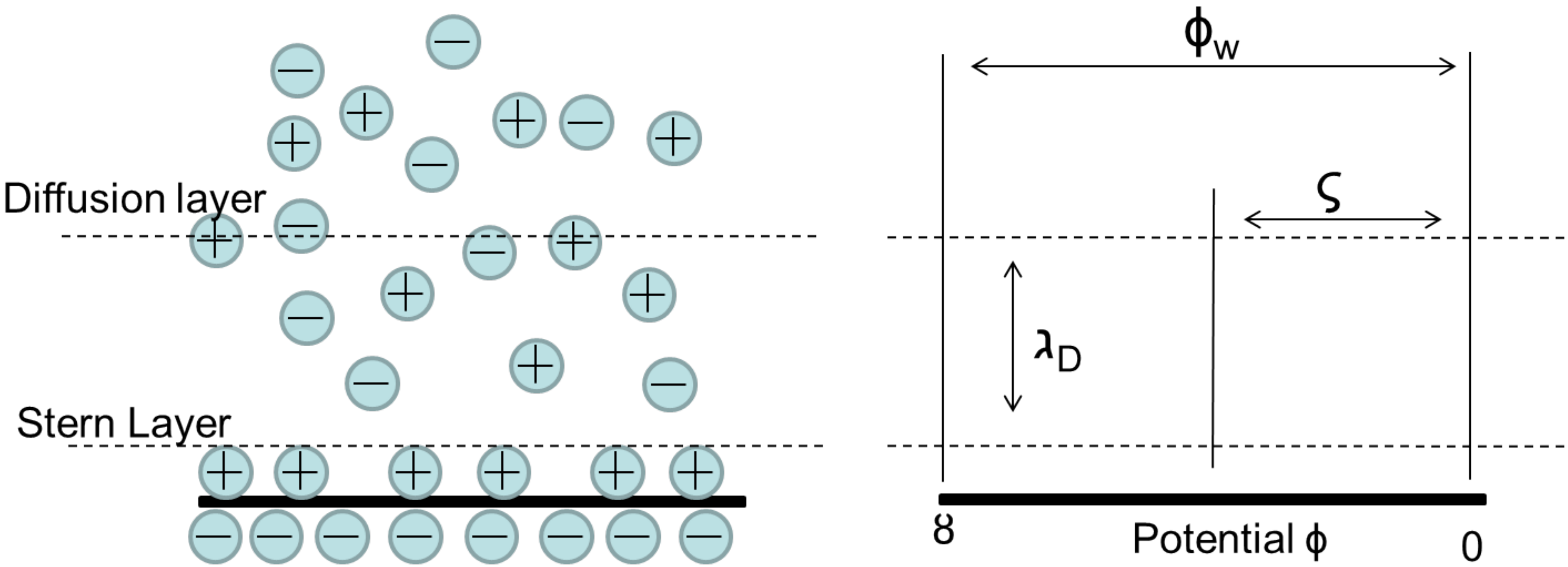

© 2018 The Pennsylvania State University

# Electro-Osmotic Flow (EOF)

- Relates greatly to electrokinetic effects
- Surface of fluid develops a charge, which influences fluid flow
- Creates different layers in the fluid which contain different charges, such as the stern and diffuse layers


© 2018 The Pennsylvania State University

# Electro-Osmotic Flow





© 2018 The Pennsylvania State University

## Advantages

- No moving parts.
- No wear.
- Low diffusion of the laminar flow.
- Simple design.

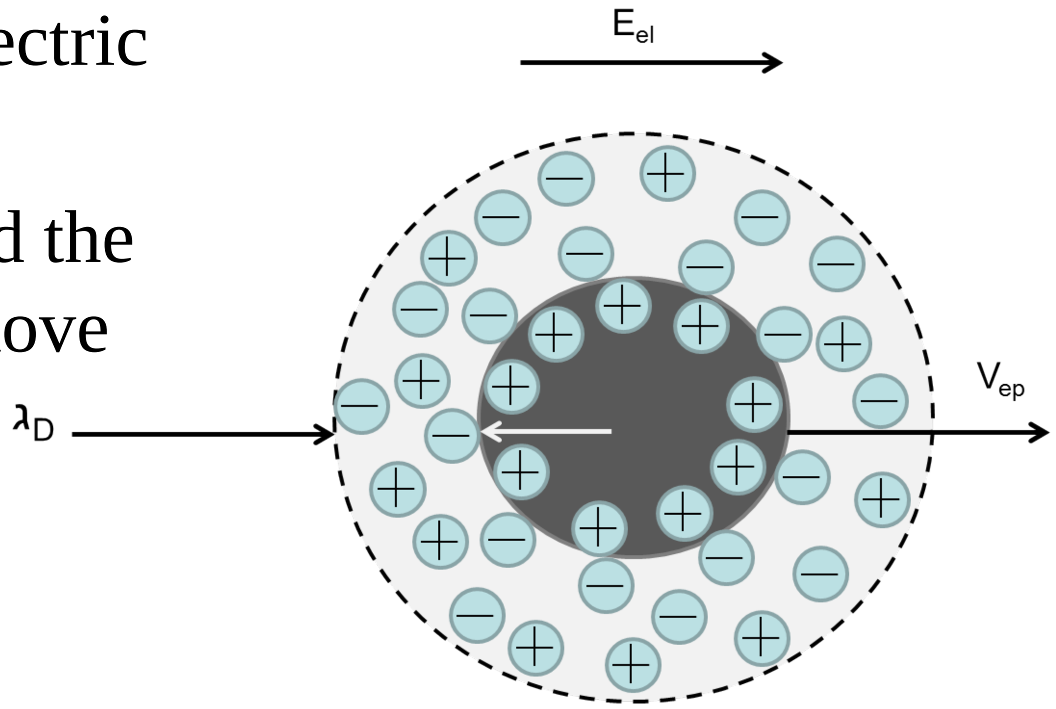
## Disadvantages

- High voltages (100’s – 1000’sV) makes it difficult to miniaturize.
- Chemical absorption to the channel walls.
- Sensitive to fluid and channel chemistry.
- Joule heating.


© 2018 The Pennsylvania State University

# Electrophoresis

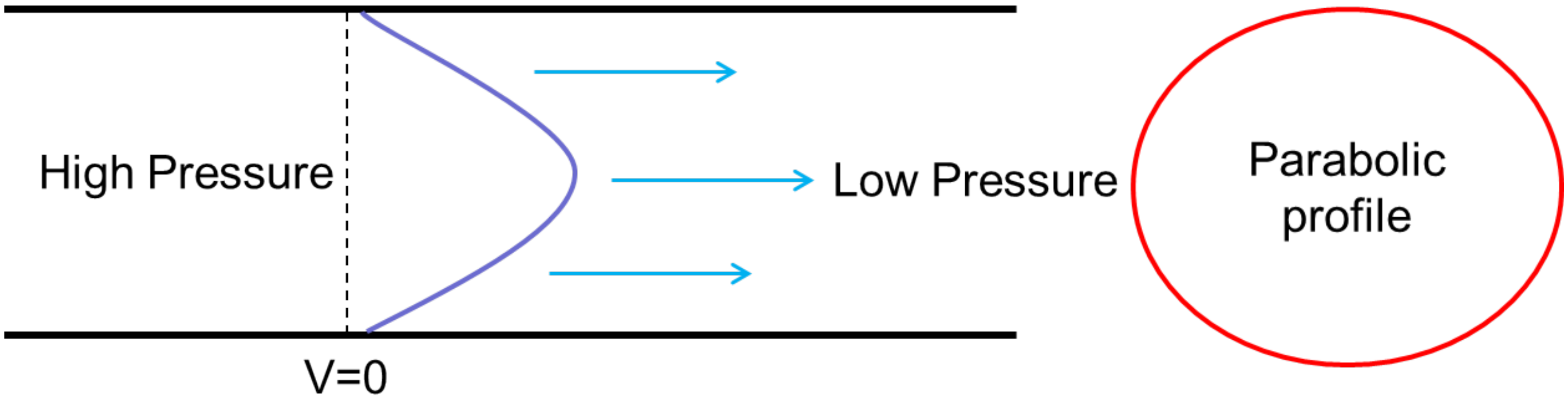
- Movement of charged particles or molecules that are subjected to an electric field
- “Cations move toward the cathode and anions move toward the anode.”



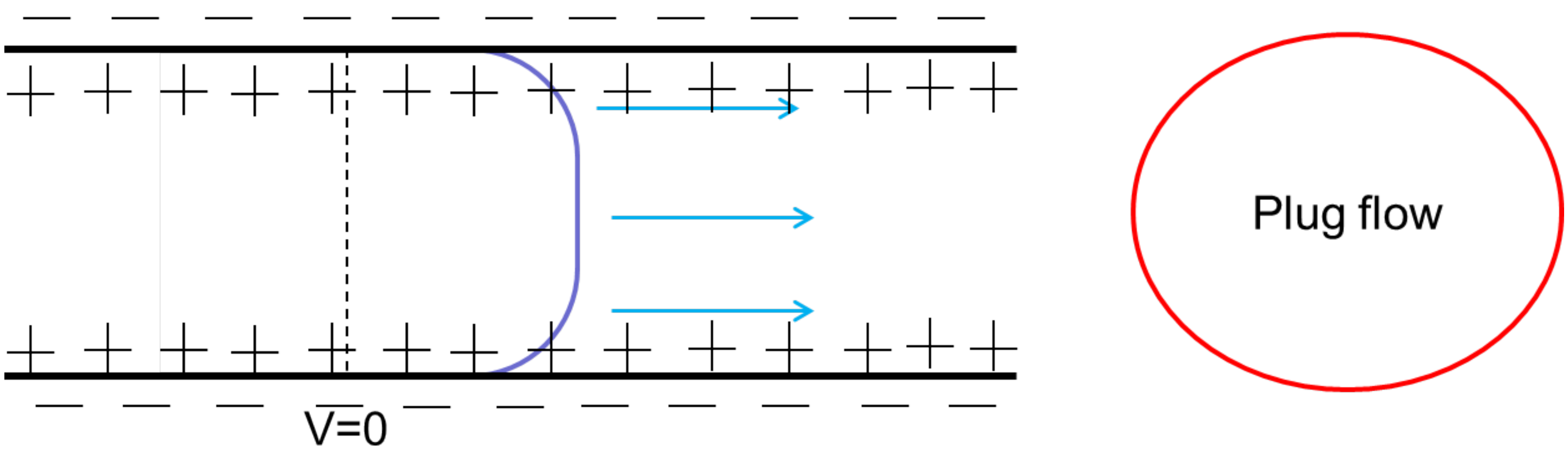


© 2018 The Pennsylvania State University

## Syringe Pump (pressure or electrophoresis driven)




## Applied Potential (electro-osmotic flow)





© 2018 The Pennsylvania State University

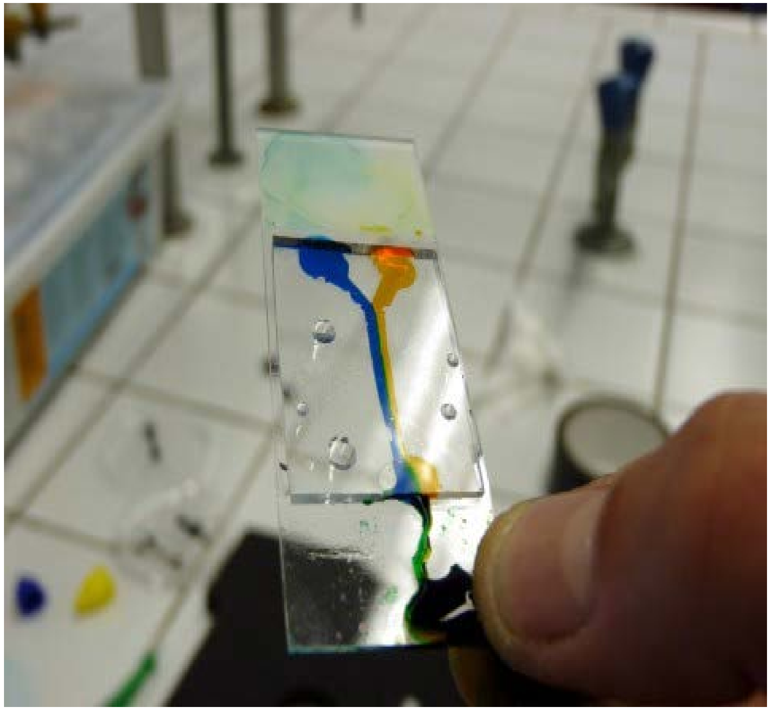
# Some Non-ideal Considerations

- Generally fluids at the micro scale do not want to mix
- Pressure wave affects mixing
- Curves in the design may cause mixing
- Materials may have intrinsic properties that cause mixing or non-mixing
- Because there are many variables, computer simulations are often used in the design of microfluidics


© 2018 The Pennsylvania State University

# Laminar Flow

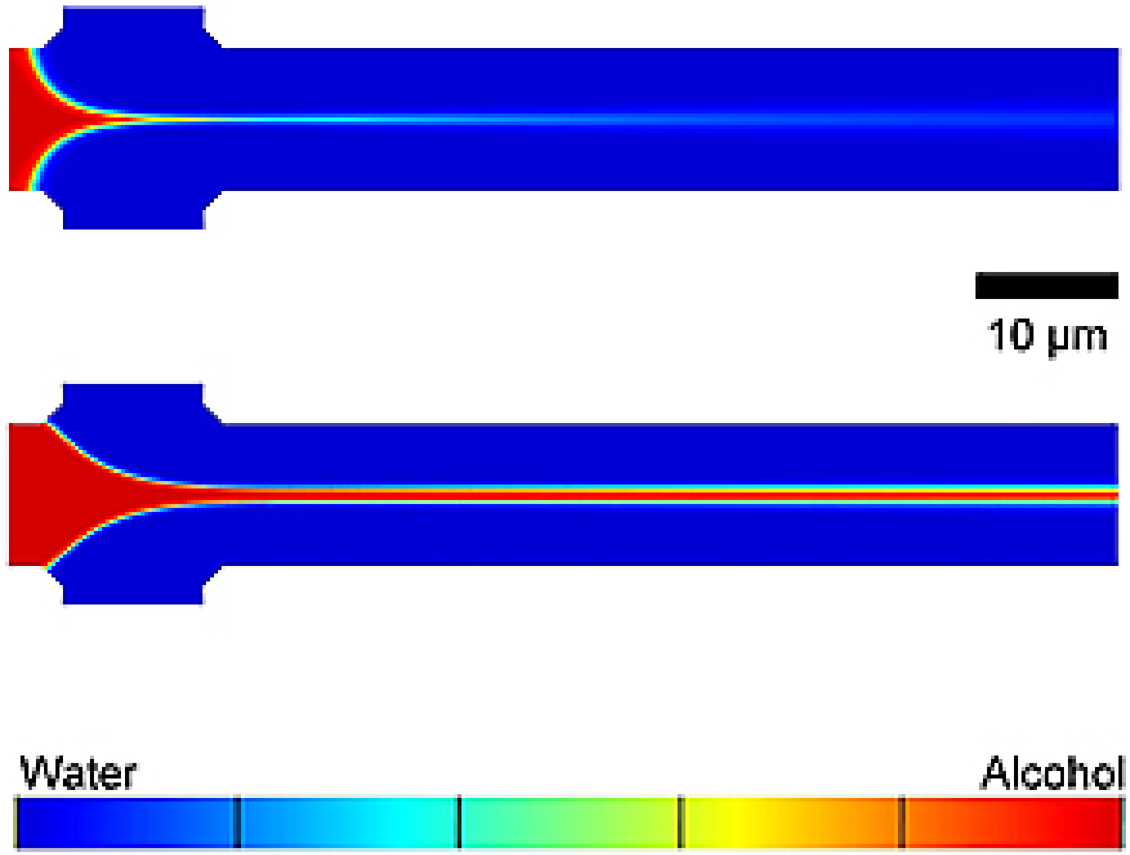
- When all of the fluid particles move in paths parallel to the overall flow direction.
- At the extremely small scale, fluids exhibit characteristics of laminar flow.
  - When multiple fluids are introduced, they want to flow in straight lines with little to no mixing occurring.



http://wetpong.net/wetpong


© 2018 The Pennsylvania State University

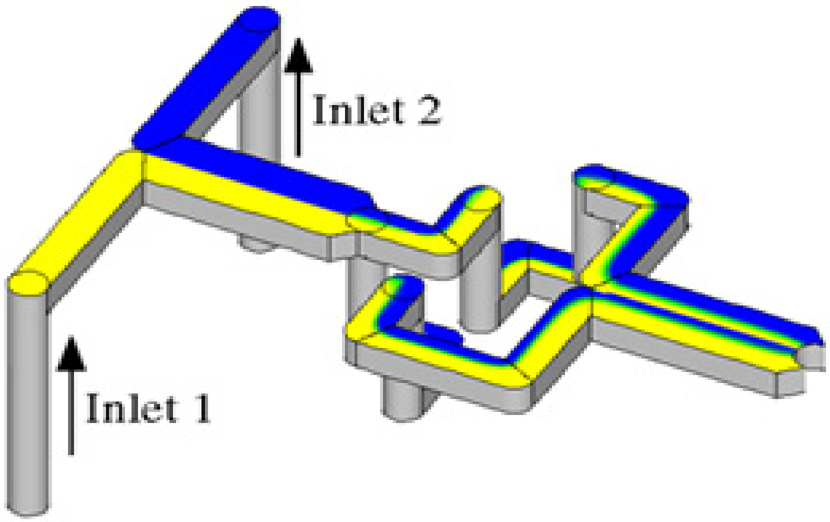
# Laminar Flow




http://www.nist.gov/pml/div683/command_042710.cfm


© 2018 The Pennsylvania State University

# Laminar Flow




- Laminar flow is the norm, and it is often not desired in a device
- No turbulence
- Fluids mix by diffusion only
- Can be useful for fluid control, but makes solution formation difficult

Multi-level laminating mixer
Gray et al., Sens. Actuators, A 77, 1999


© 2018 The Pennsylvania State University

# Fluid Mixing

- Dealing with liquids in the amounts of nanoliters
  - 30 nL = 1/1000$^{th}$ of 1 droplet
- Reactions occur in milliseconds
- Macro mixing methods are difficult to miniaturize to this scale, smaller channels have laminar flow
- Generally bends, turns, and increasing channel dimensions increase mixing


© 2018 The Pennsylvania State University

# Reynolds Number

- "Quick check number" used to determine if a fluid will have laminar or turbulent characteristics
- Represents a ratio of momentum forces to viscous forces in fluid (liquid or gas) flow
- Expresses the relationship of fluid density, velocity, channel dimensions, and viscosity coefficient. There are other variables that are not considered by this quick check equation.
- Named after Osborne Reynolds (1824-1912)


© 2018 The Pennsylvania State University

# Reynolds Number

Quick approximation to determine whether the flow of a typical fluid is laminar or turbulent.

- D = Pipe Diameter
- V = Fluid Velocity
- p = Fluid Density
- μ = Fluid Viscosity

$$\mathbf{Re} = \frac{\mathbf{D.V.}\boldsymbol{\rho}}{\boldsymbol{\mu}}$$


© 2018 The Pennsylvania State University

# Reynolds Number

- Liquids flow smoothly when they have a low Reynolds Number
- Microchannels with only 10’s of microns in dimensions create small Reynolds Numbers creating linear, turbulent-free streams
- Mixing could be desirable to have a reaction, and low Reynolds numbers prevent mixing


© 2018 The Pennsylvania State University

# Reynolds Number

- For Laminar Flow

  Re << 1

- For Turbulent Flow

  Re >> 1

- At the extremely small scale (70 micron diameter channels) fluids will flow in a laminar fashion.
- This is a problem

  For example, for a DNA lab on a chip to work, materials must be mixed. Small channel will prevent this from happening


© 2018 The Pennsylvania State University

# Laminar flow depends upon boundary geometry

- Cylindrical pipe $Re < 2100$
- Parallel walls $Re \approx 1000$
- Wide open channel $Re \approx 500$
- Around a sphere $Re \approx 1$


© 2018 The Pennsylvania State University

# Water in a 50 ųm channel

$$Re = \frac{D.V.\rho}{\mu}$$

- D = 50 ųm
- V = 1 m/s
- p = 997.0 kg/m$^3$
- µ = .89 Pa · s

Re = .056 < 2100 = Laminar flow


© 2018 The Pennsylvania State University

# Peclet Number

- Determines whether diffusion or convection is the dominant means of mass transportation.

- Diffusion > 1
- Convection < 1

**Pe = *vl/D***

- v = velocity of the fluid
- *l* = characteristic length of the fluid
- *D* = diffusion coefficient


© 2018 The Pennsylvania State University

# Peclet Number

- When fluids flow laminarly, the primary means of mass transportation is diffusion (extremely slow process).
- To allow for mixing to occur quickly, must change flow so that it is turbulent, (meaning convection is the primary means of mass transportation).
- In the next section, mixing will be accomplished with 90-degree bends to create fluid convection.


© 2018 The Pennsylvania State University

# Outline

- Microfluidics Overview
- Physics of Microfluidics
- Operational Components
  - Micro pumps
  - Mixers / stirrers
  - Valves
- Materials and Applications


© 2018 The Pennsylvania State University