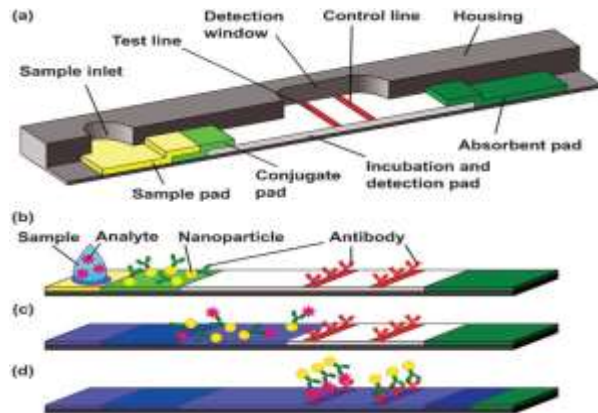
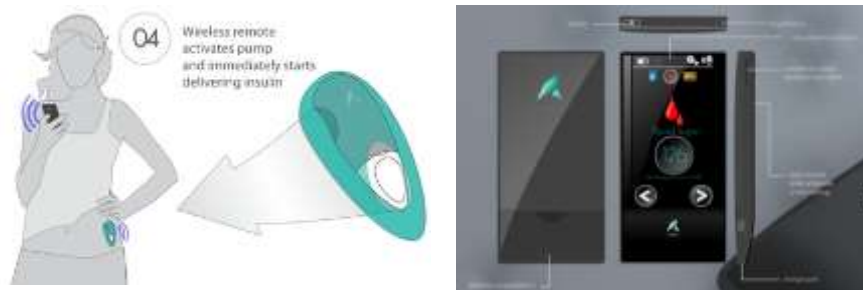


Applications of Microfluidics / Nanofluidics

Test Strips / Lateral Flow Tests



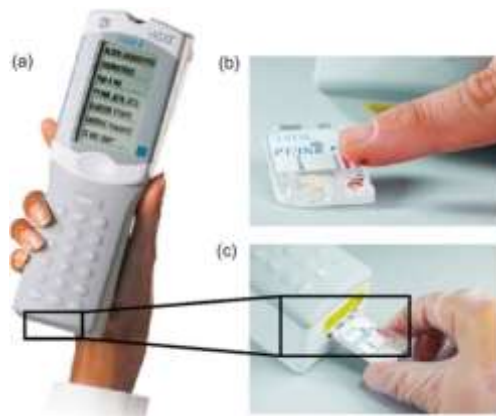
Tolea insulin sensor / pump



(with gecko feet micro-needle attachment)

<http://www.yankodesign.com>

i-STAT handheld blood analyzer



Waterproof epidermal microfluidic biomarker sensor



Reeder *et al.* *Sci. Adv.* **5** (2019)
DOI: 10.1126/sciadv.aau6356

<https://www.pointofcare.abbott/us/en/offerings/istat>
Mark *et al.* *Chem. Soc. Rev.* **39** (2010)
DOI: 10.1039/B820557B

Applications of Microfluidics / Nanofluidics

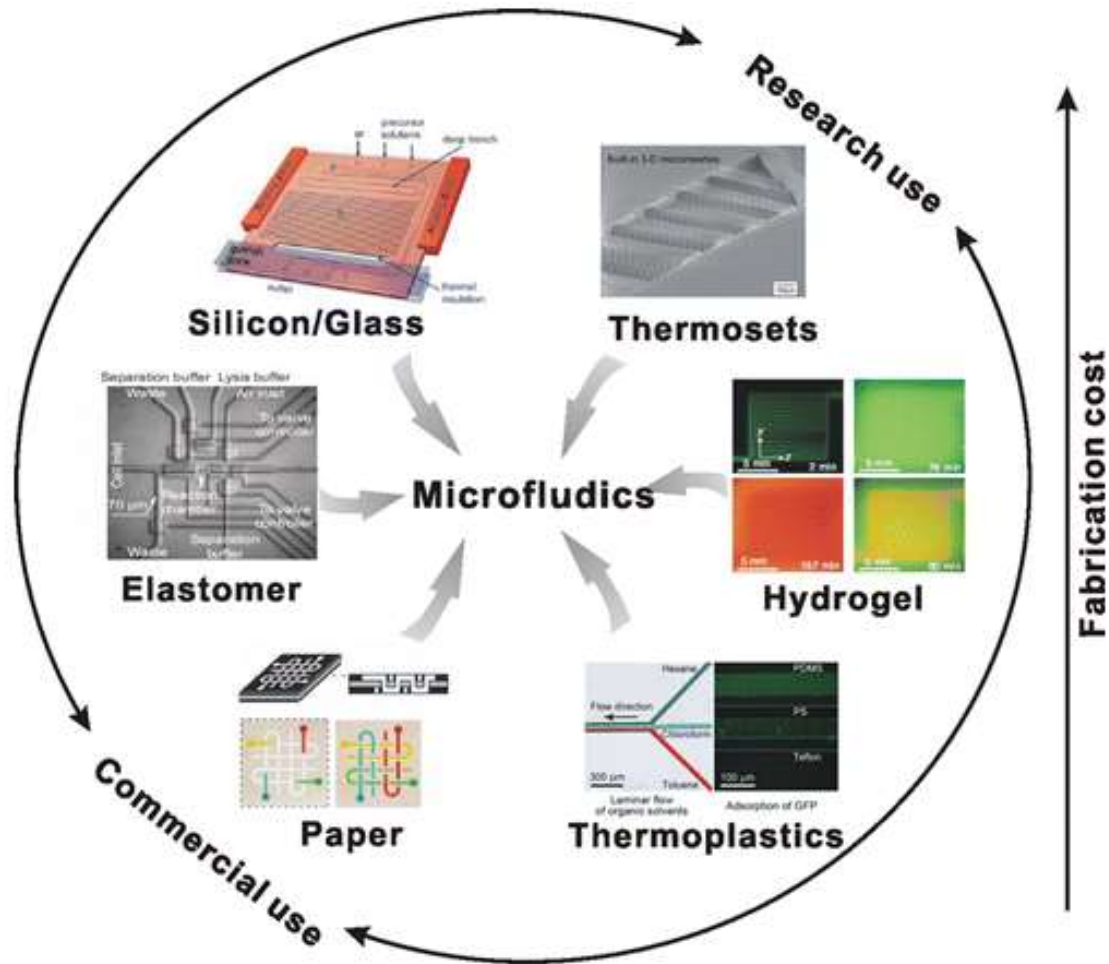
(Desired) benefits

- Higher sensitivity
- Faster system response
- Low fluid volumes consumption
- High throughput analysis
- Controlled microenvironments for studies of fundamental cell biology
- Lower costs
- Realization as **lab-on-a-chip**!



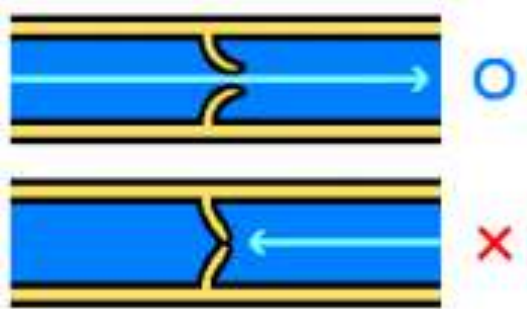
<http://www.gene-quantification.de/lab-on-chip.html>

Microfluidics: Materials



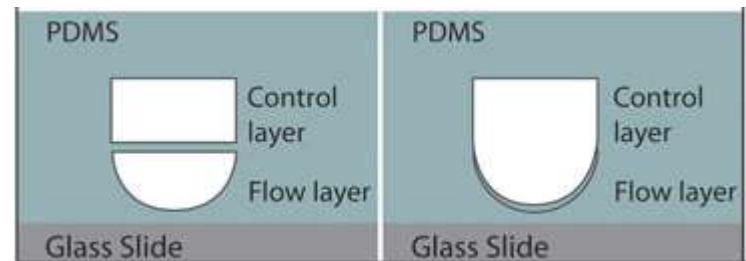
- Greatly amplified material properties
- Specific microfabrication strategies
- Elastomers and plastics are both rather cheap and allow fast microfabrication

Components: Valves

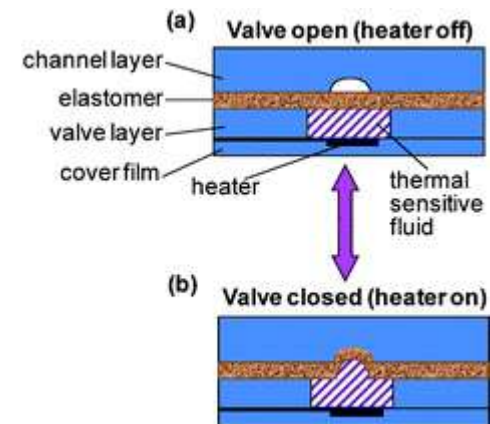


http://www.labautopedia.org/mw/Microfluidic_sample_transport

- Passive vs active valves
- Passive: one flow direction, closing/opening by backward pressure
- Active: several operation modes (piezoelectric, magnetic etc.)

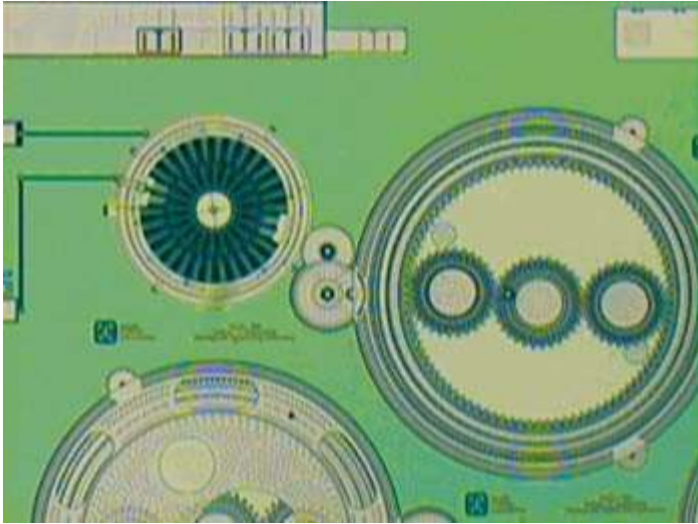


San-Miguel *et al.* 2013 [http://www.wormbook.org/DOI: 10.1895/wormbook.1.162.1](http://www.wormbook.org/DOI:10.1895/wormbook.1.162.1)

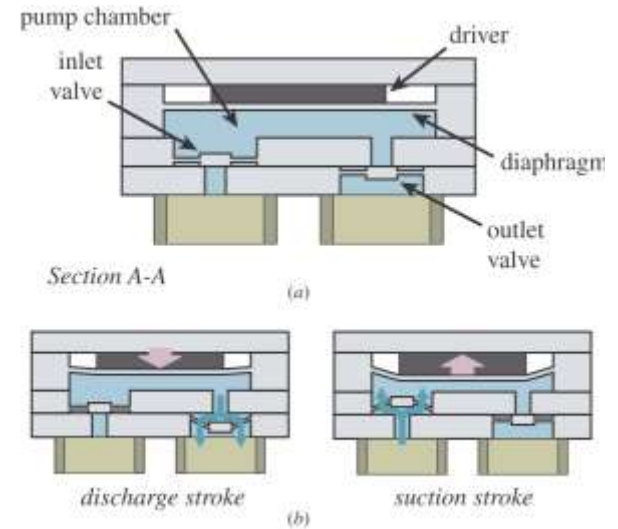


Pitchaimani *et al.* Lab Chip **9** (2009)
DOI: 10.1039/B909742B

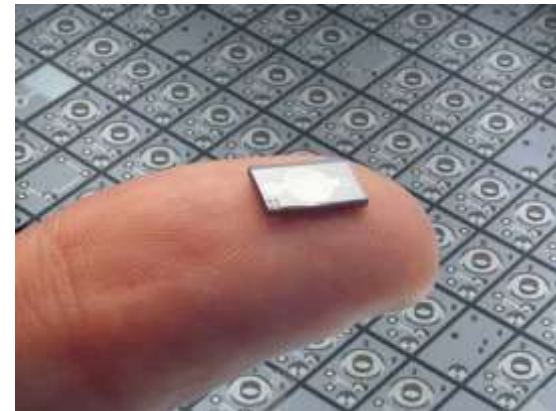
Components: Pumps?



<http://www.rinr.fsu.edu/fall2002/images/nanopump.jpg>

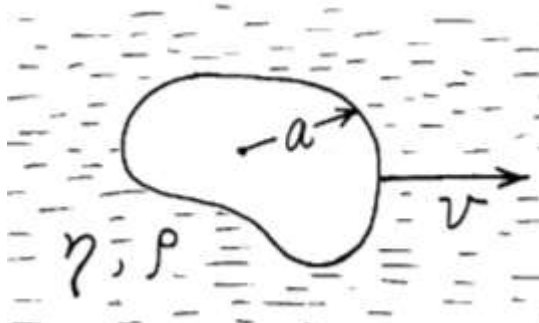


Laser et al. *J. Micromech. Microeng.* **14** (2004)
<http://dx.doi.org/10.1088/0960-1317/14/6/R01>



<http://cdn.medgadget.com/img/524deb1.jpg>

Physical basics: The Reynolds number

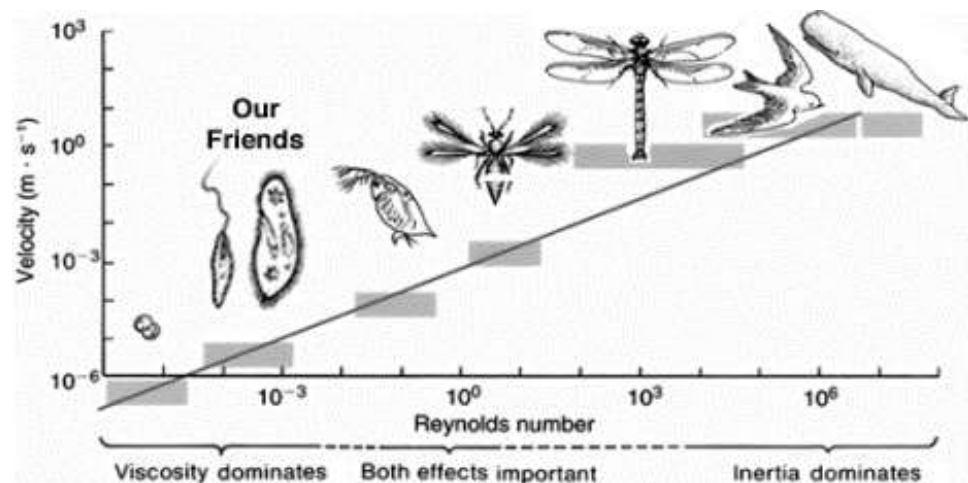
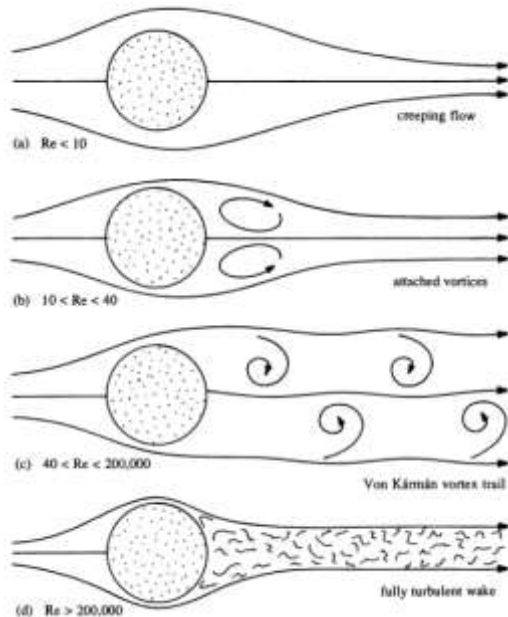


E.M. Purcell, Am. J. Phys. 45 (1977)
 "Life at low Reynolds number"
 DOI: 10.1119/1.10903

For decreasing system size:

- Viscous forces $\uparrow$
- Inertial forces $\downarrow$
- Reynolds-Number:

$$Re = \frac{\rho a v}{\eta} \sim \frac{\text{inertial forces}}{\text{viscous forces}}$$



http://www.cabrillo.edu/~jcarothers/lab/notes/protopara/VISUALS/images/MainFrame_clip_image002_0000.png

Physical basics: The Reynolds number

$$\text{Re} = \frac{\rho a v}{\eta} \quad \text{large}$$



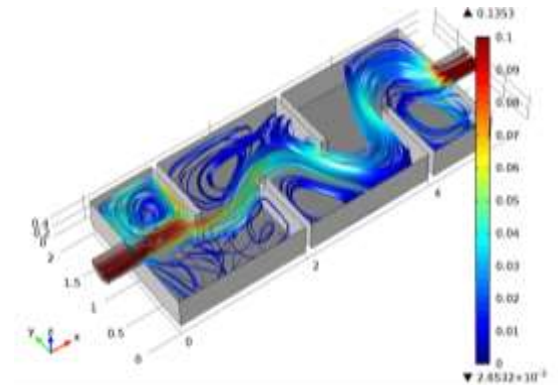
<https://i.stack.imgur.com/Sj7a7.jpg>



<http://eoimages.gsfc.nasa.gov/images/imagerecords/7200/072646/CapeVerde.A2005005.1225.250m.jpg>



<http://kevingaskell.com/wp-content/uploads/2017/04/Turbulence-550pxls.jpg>



<https://www.comsol.com/multiphysics/navier-stokes-equations>

Physical basics: The Reynolds number

$$Re = \frac{\rho a v}{\eta} \quad \text{small}$$



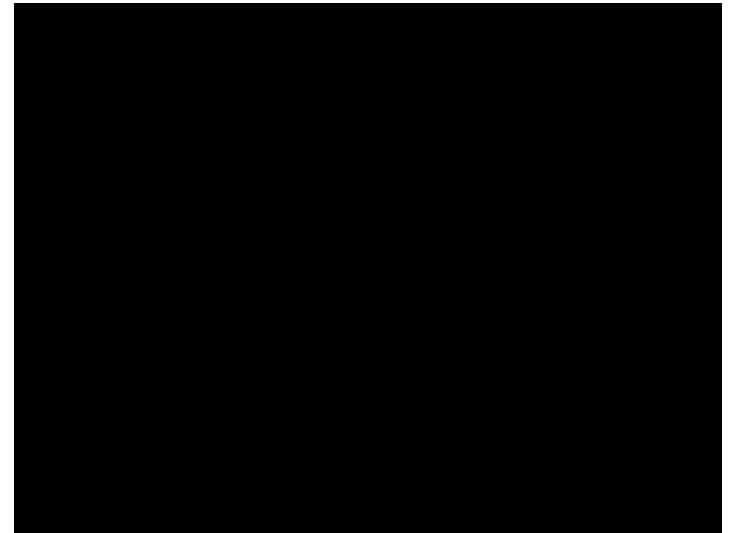
<https://www.goodground.com/wp-content/uploads/2017/08/honey.jpg>



<https://www.youtube.com/watch?v=GxthWm3F96Q&t=189s>



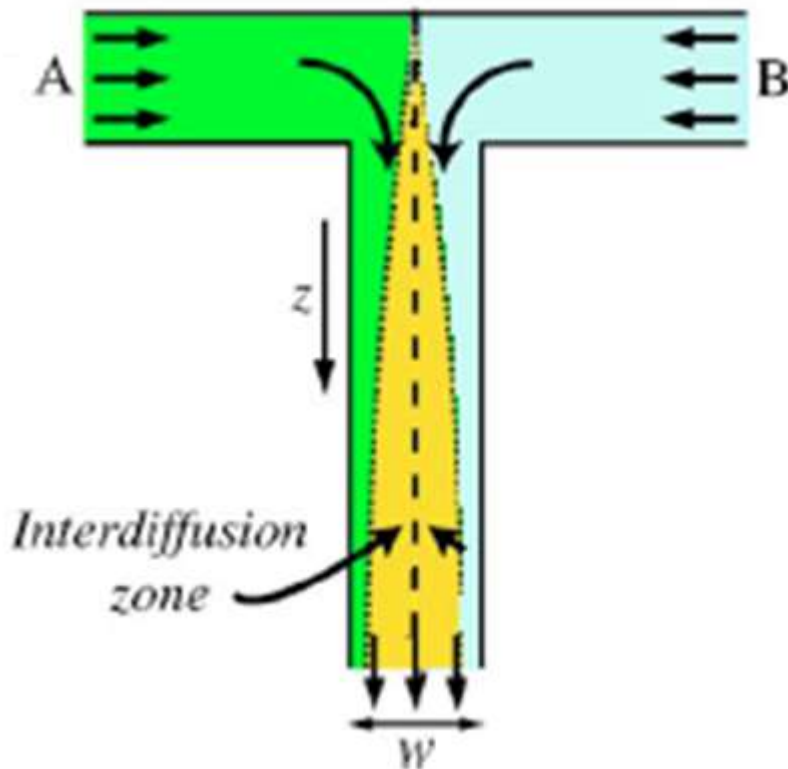
<https://www.youtube.com/watch?v=UpJ-kGI1074>



<https://www.youtube.com/watch?v=hHSbdbQHk9M>

Components: Mixers

Problem in microfluidics: Low $Re \rightarrow$ no turbulence !
Must mix via diffusion !



$$\tau_D \sim w^2 / D$$

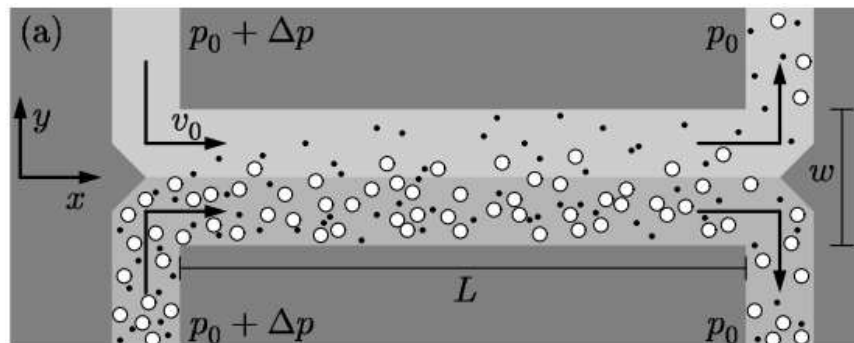
$$Z \sim \tilde{U}_0 w^2 / D$$

$$\frac{Z}{w} \sim \frac{U_0 w}{D} \equiv \text{Pe} \quad \text{Péclet number}$$

Components: Mixers / Filters

The H-Filter:

- Solution with 2 types of particles of different Pe -numbers (small, large)
- The particles with the smaller Pe -number diffuse faster the channel (upper/right area) $\rightarrow$ can be extracted

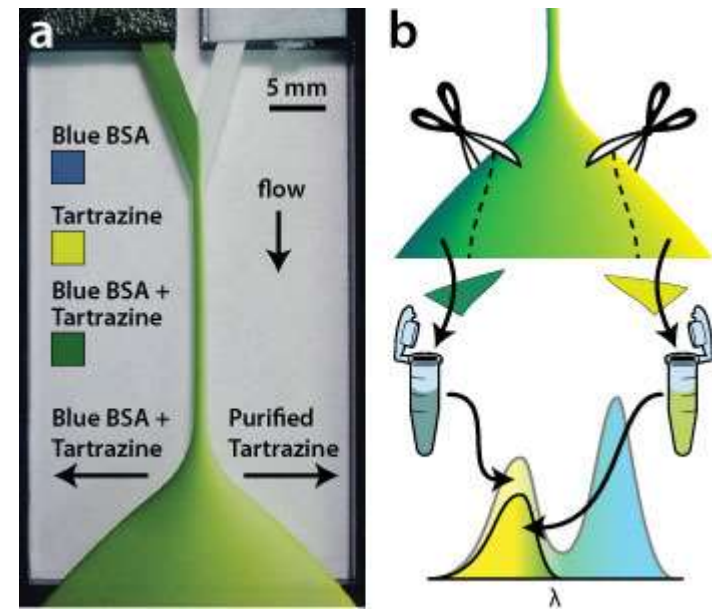


$$\tau_{\text{conv}} = \frac{L}{v_0}$$

$$\tau_{\text{diff}} = \frac{\left(\frac{1}{2}w\right)^2}{D} = \frac{w^2}{4D}$$

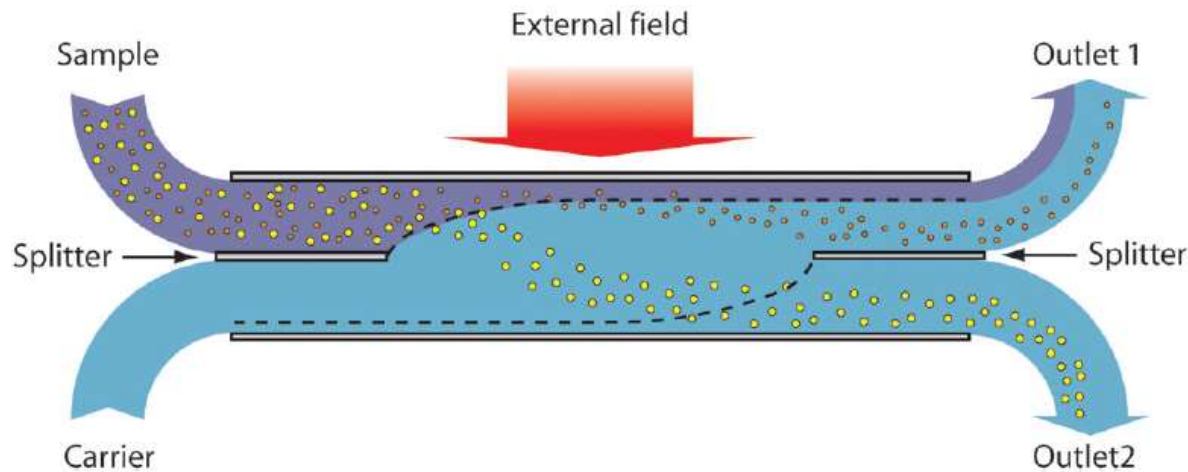
$$\tau_{\text{diff}}(D^*) = \tau_{\text{conv}}$$

$$D^* = \frac{v_0 w^2}{4L}$$



<http://www.mf20.org/applications/extracting-analytes-h-filter>

Components: Separators



(Lenshof and Laurell 2010)

- Active separation using external fields
- External force may be magnetic, dielectrophoretic, acoustic etc.



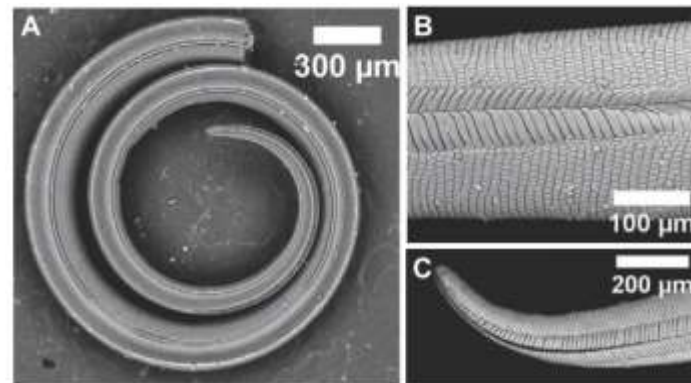
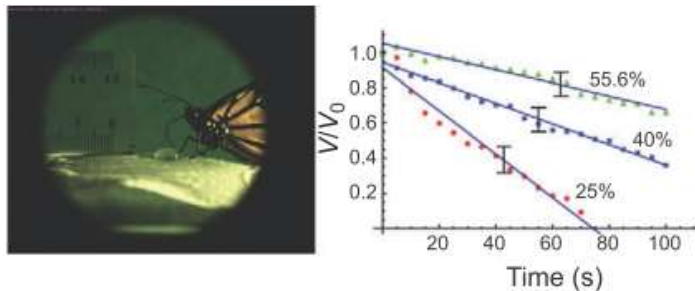
<http://www.youtube.com/watch?v=RNpwgHCB5hQ>

Hagen-Poiseuille Law?

Paradox of drinking-straw model
of the butterfly proboscis



<https://ak7.picdn.net>



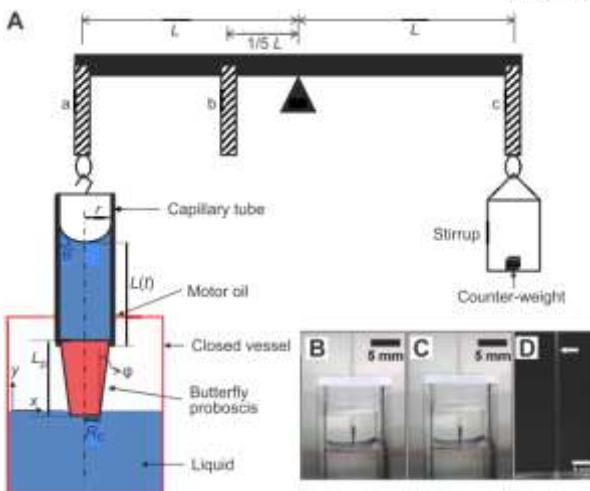
Shark skin-inspired surfaces



- Swimming suits...
- Airbus A320 with riblet foil

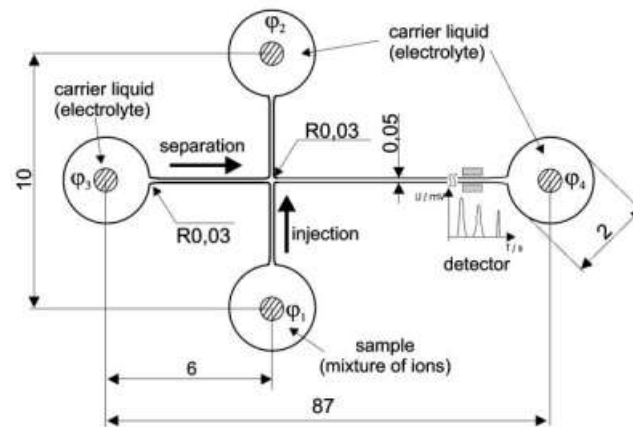
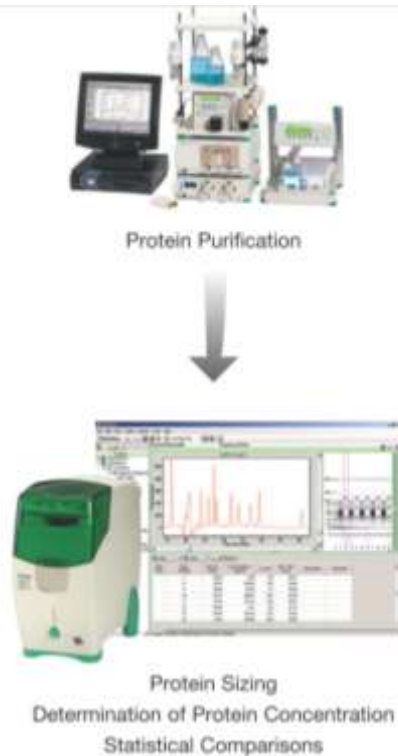


Müller, Phys. J. **17** (2018)
Domel *et al.* J. R. Soc. Interface **15** (2018)
DOI: 10.1242/jeb.097998



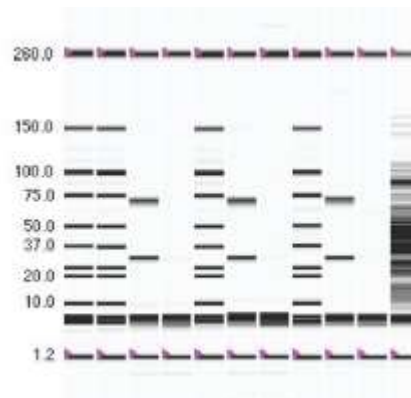
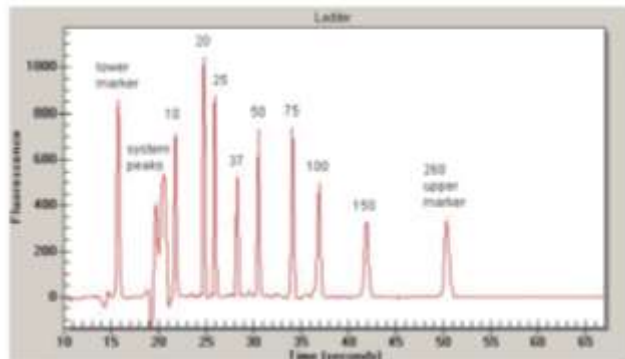
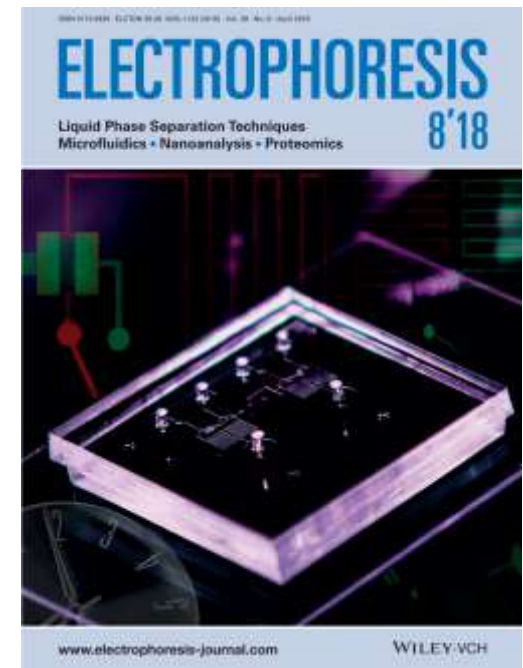
Tsai *et al.* J. Exp. Biol. **217** (2014)
DOI: 10.1242/jeb.097998
SPIE article, DOI: 10.1117/2.1201604.006419

Electrophoresis



Barz *et al.* Lab Chip **5**, 949-958 (2005).

Good review: Pagaduan *et al.* Anal. Bioanal. Chem. **407**, 6911-6922 (2015). DOI: 10.1007/s00216-015-8622-5



Why usually gel EP?

Mobility of DNA in Liquid

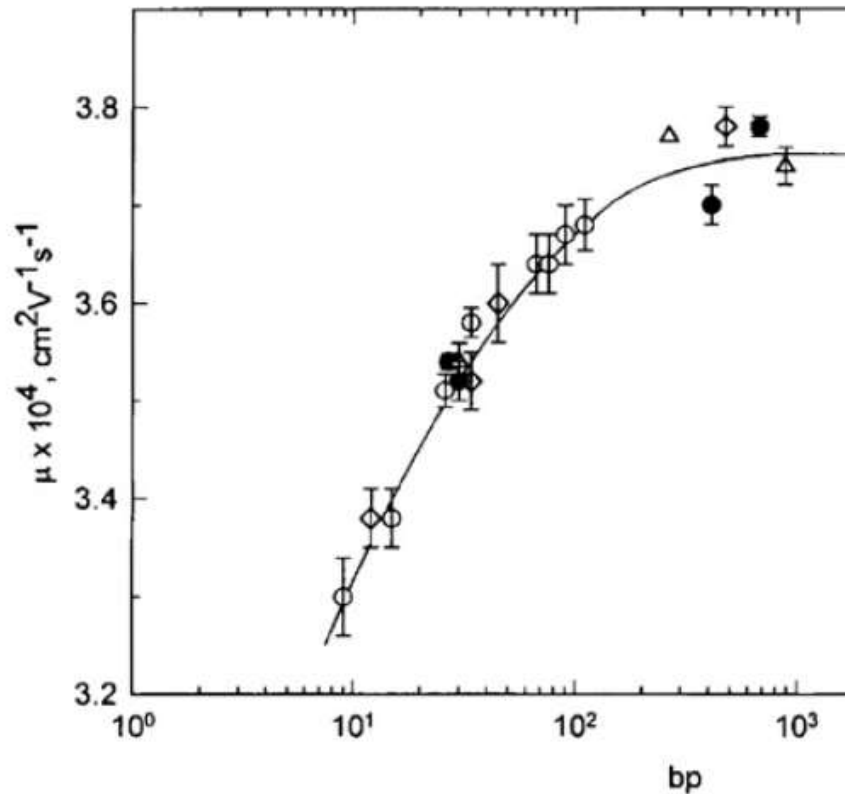


Fig. 4 The free solution electrophoretic mobility of DNA molecules in TAE buffer. As can be clearly seen in this graph, the DNA molecules reach a plateau phase around a size of 400 bp. The plateau electrophoretic mobility here is $\sim 3.75 \times 10^{-4} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$. Thus, larger fragments cannot be separated from each other. Reprinted with permission of John Wiley & Sons, Inc.⁶⁰

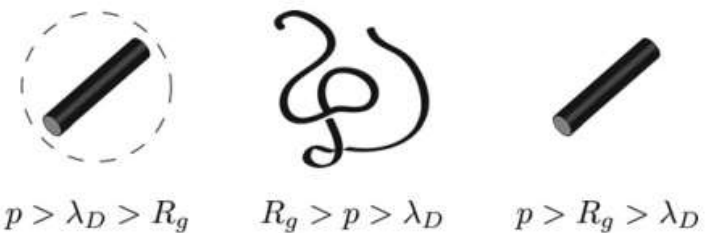


Fig. 5 The three different regimes of (bio) polymers in free solution. In regime A, the molecule can be treated as a charged rod in a sphere. Here, $p > \lambda_D > R_g$. Here separation is possible. In regime B, the molecule can be seen as a random coil, $R_g > p > \lambda_D$. In regime C, the molecule is seen as a long rod, where $p > R_g > \lambda_D$. In regimes B and C, no separation is possible. Image after ref. 75.

Mobility of DNA in Gel

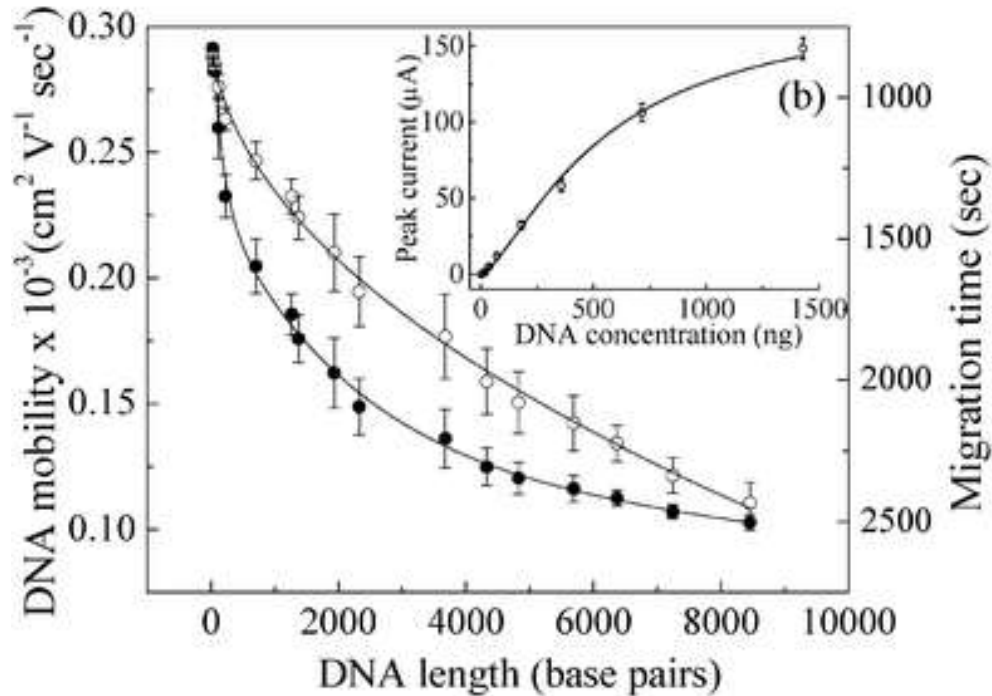
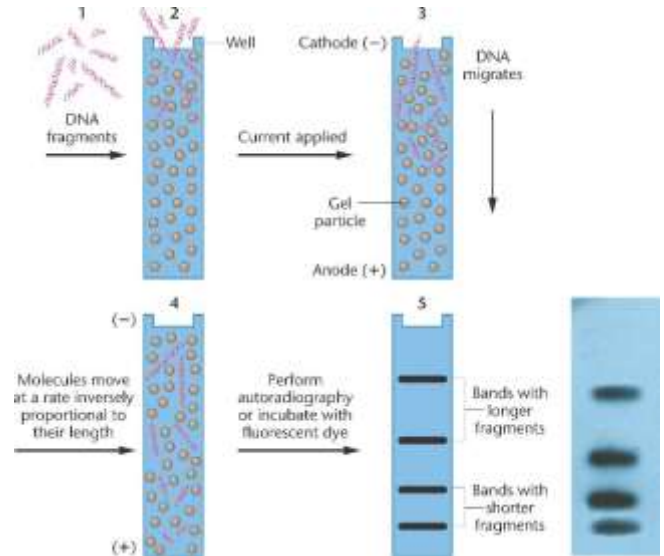
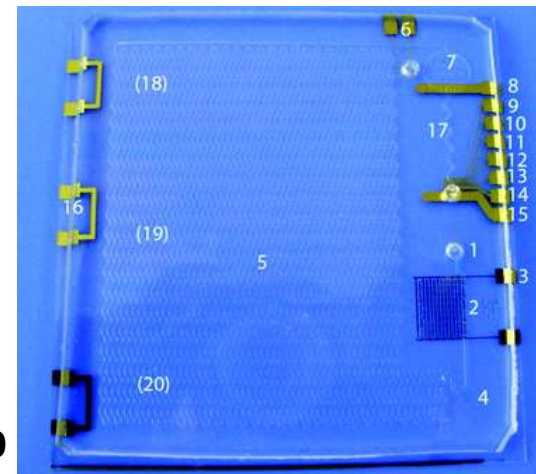


Fig. 4 Mobility of DNA (—●—) and DNA migration time (—○—) for different lengths of DNA fragments, (inset to b) concentration of DNA sample vs. averaged response peak (calculated for 117 bp peak).

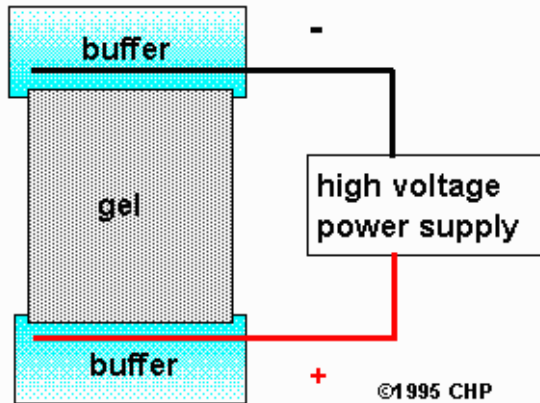


<http://bio3400.nicerweb.com>

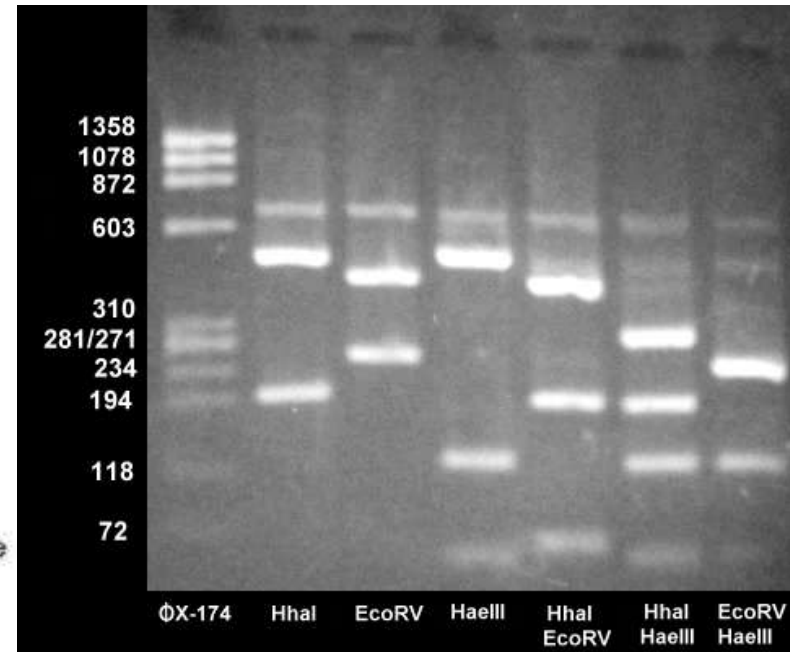
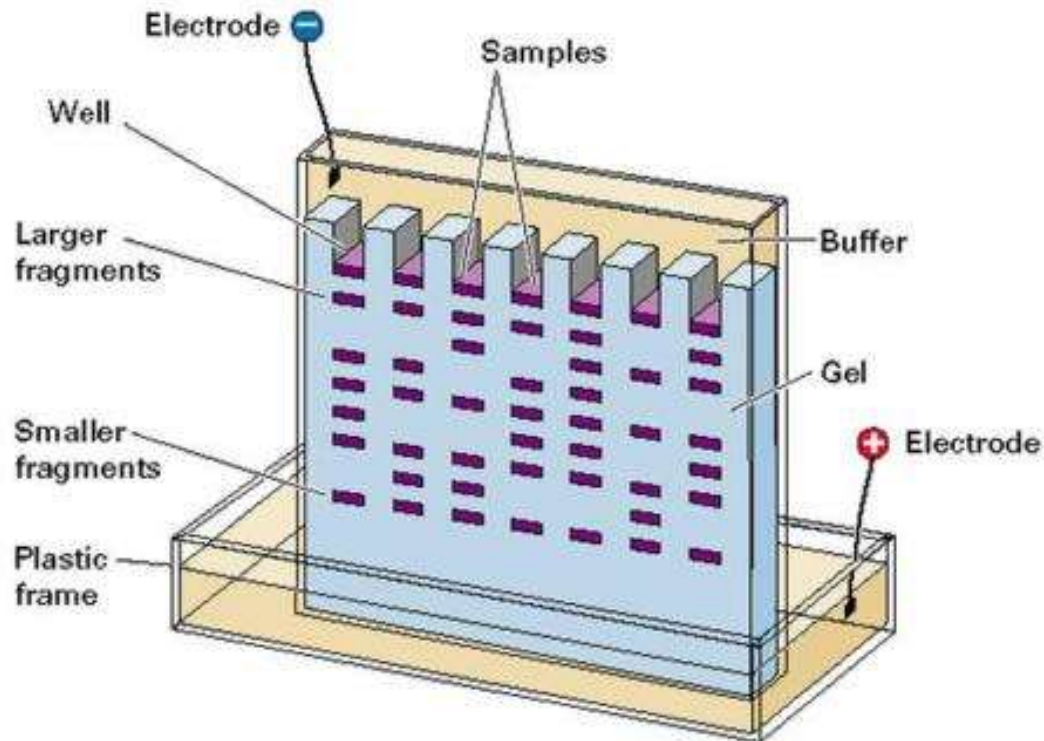


PCR microfluidic chip

Gel Electrophoresis

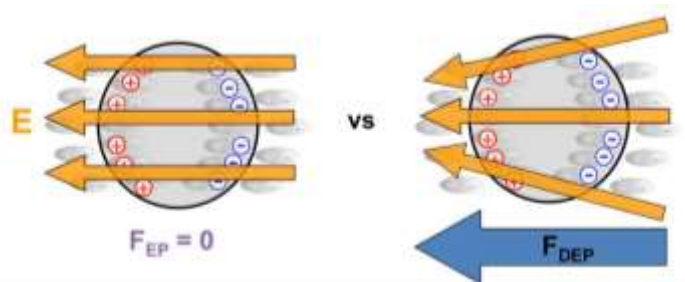
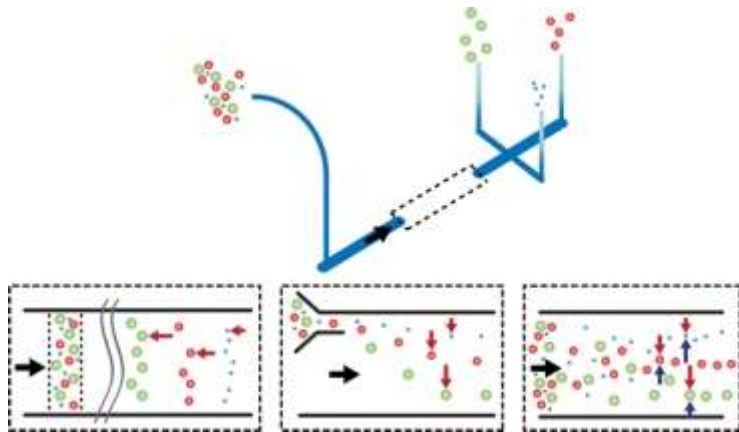


<http://1.bp.blogspot.com>



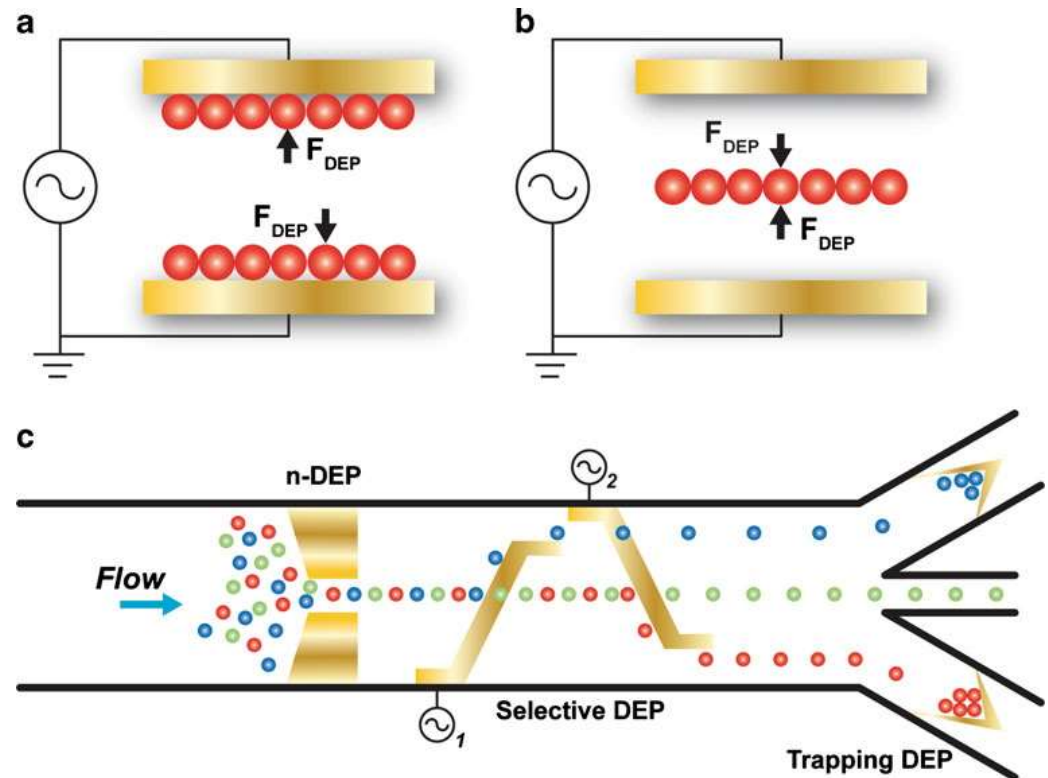
http://www.mun.ca/biology/scarr/Lab_5_gel_1999.gif

Dielectrophoresis



<https://pratted.wordpress.com/tag/dielectrophoresis/>

AC-DEP



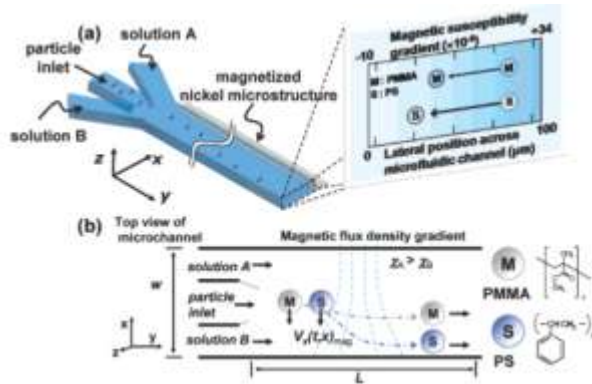
$$F(\omega) = 2\pi\epsilon_m r^3 \left(\text{Re}[f_{CM}] \nabla E_{RMS}^2 - \frac{2\pi}{\lambda} \text{Im}[f_{CM}] E_{RMS}^2 \right)$$

Review: Gossett *et al.* Anal. Bioanal. Chem. **397** (2010)

<http://www.elveflow.com/microfluidic-tutorials/cell-biology-imaging-reviews-and-tutorials/microfluidic-for-cell-biology/label-free-microfluidic-cell-separation-and-sorting-techniques-a-review/>

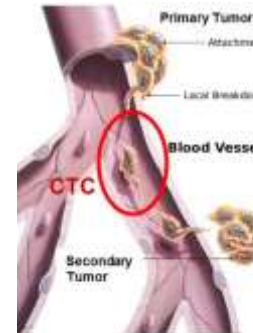
Magnetophoresis

Magnetophoresis of Microparticles



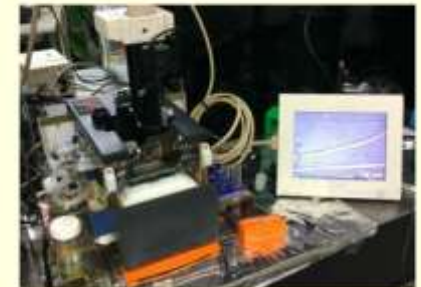
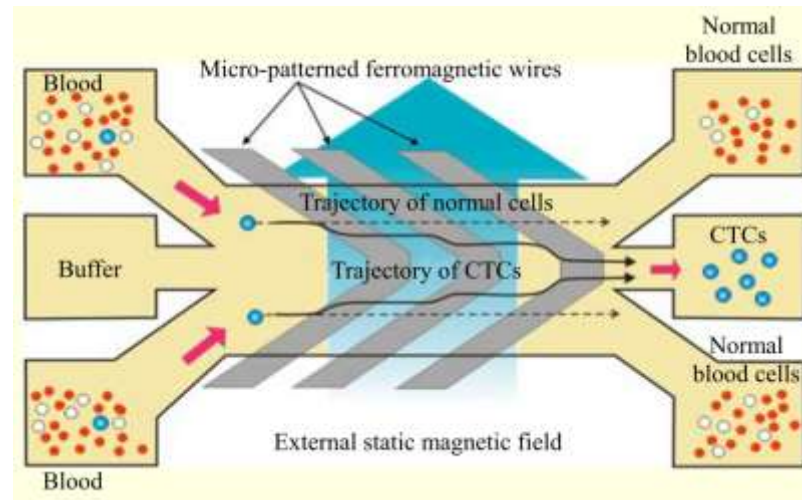
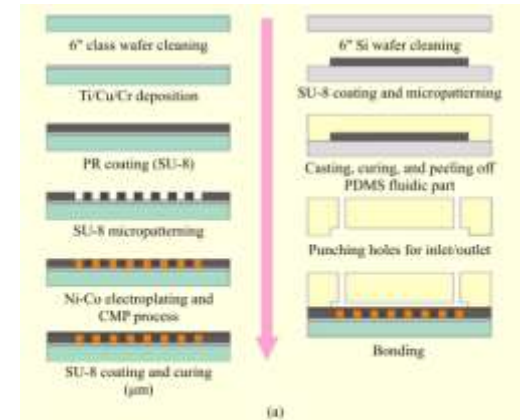
Kang *et al.* JACS **130** (2008)

Magnetophoresis of Circulating Tumor Cells



Adapted from National Cancer Institute

<https://www.linkedin.com>



Park *et al.* ETRI Journal **37** (2015)