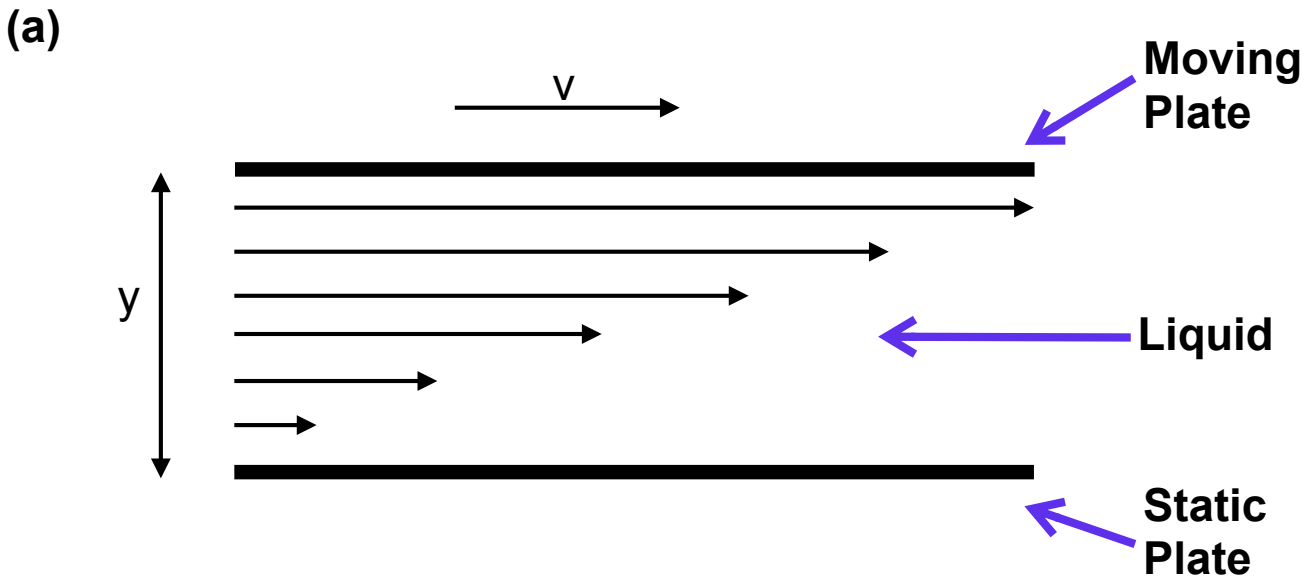
Physics of Life

PHYS-468

Hydrodynamic Methods

Henning Stahlberg,
LBEM, IPHYS, SB, EPFL

Dynamic Viscosity



$$f = \eta_s \cdot A \cdot \frac{dv}{dy}$$

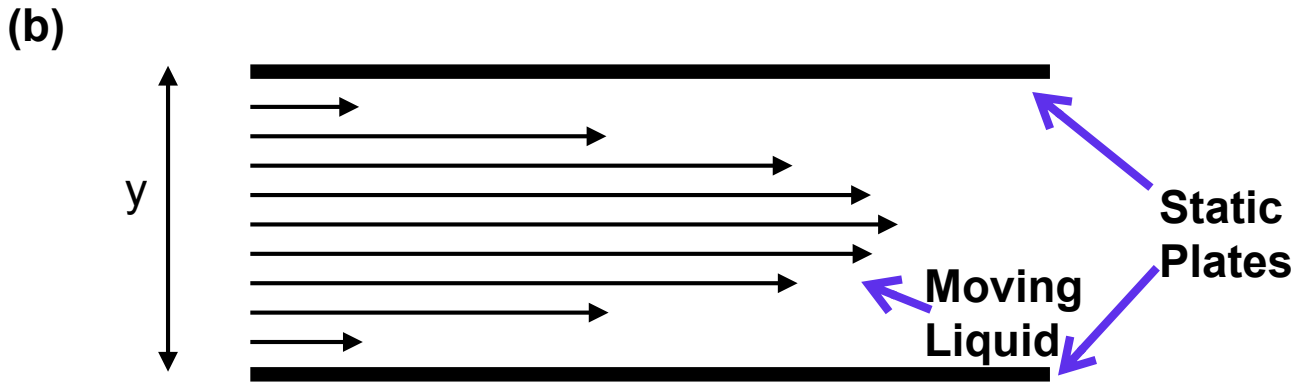
f = Shear force

η_s = Dynamic viscosity of solution

A = Area of layers of liquid

v = Velocity

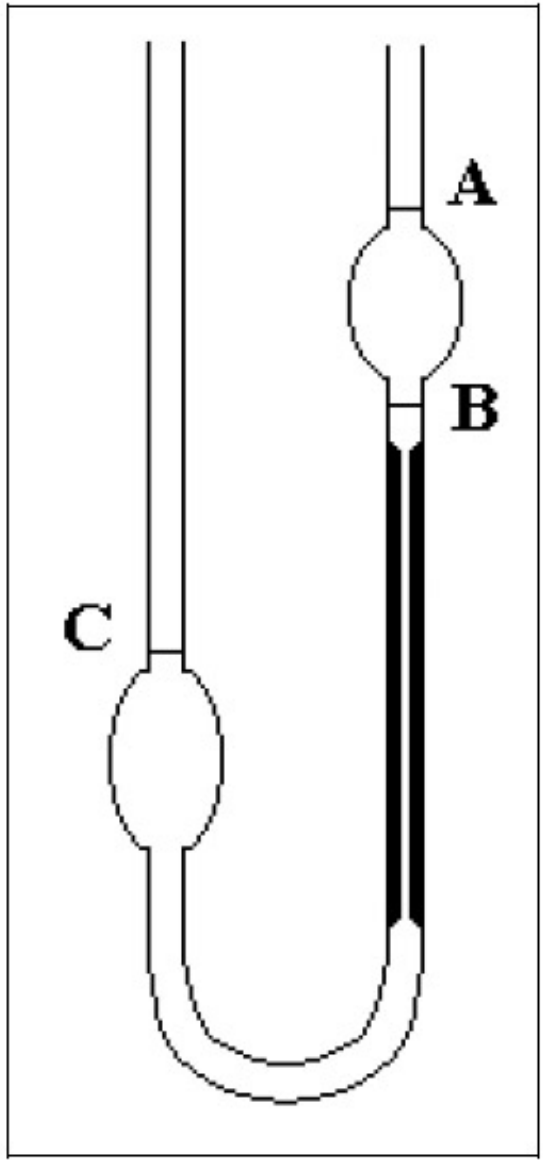
y = Vertical direction accross flow



$$\tau = \eta_s \cdot \frac{dv}{dy} = \frac{f}{A}$$

Viscosity. (a) A linear shear gradient dv/dy is established between two plates, one moving at speed v, and the other one immobile. (b) A parabolic shear gradient is formed, when liquid flows between two immobile plates.

Ostwald or Ubbelohde Viscometer



Ostwald Viscometer

Fill solution into left tube until the liquid level is at C.

Apply suction at right tube until liquid level reaches A.

Measure the time *t* it takes for the liquid to flow back below level B, and calculate the **dynamic viscosity**:

$$t = \frac{8 \cdot L \cdot V \cdot \eta_S}{\pi \cdot h \cdot g \cdot r^4 \cdot \rho}$$

$$\eta_S = \frac{\pi \cdot h \cdot g \cdot r^4}{8 \cdot L \cdot V} \cdot \rho \cdot t$$

η = dyamic viscosity

h = average height between liquid surfaces

g = gravity constant

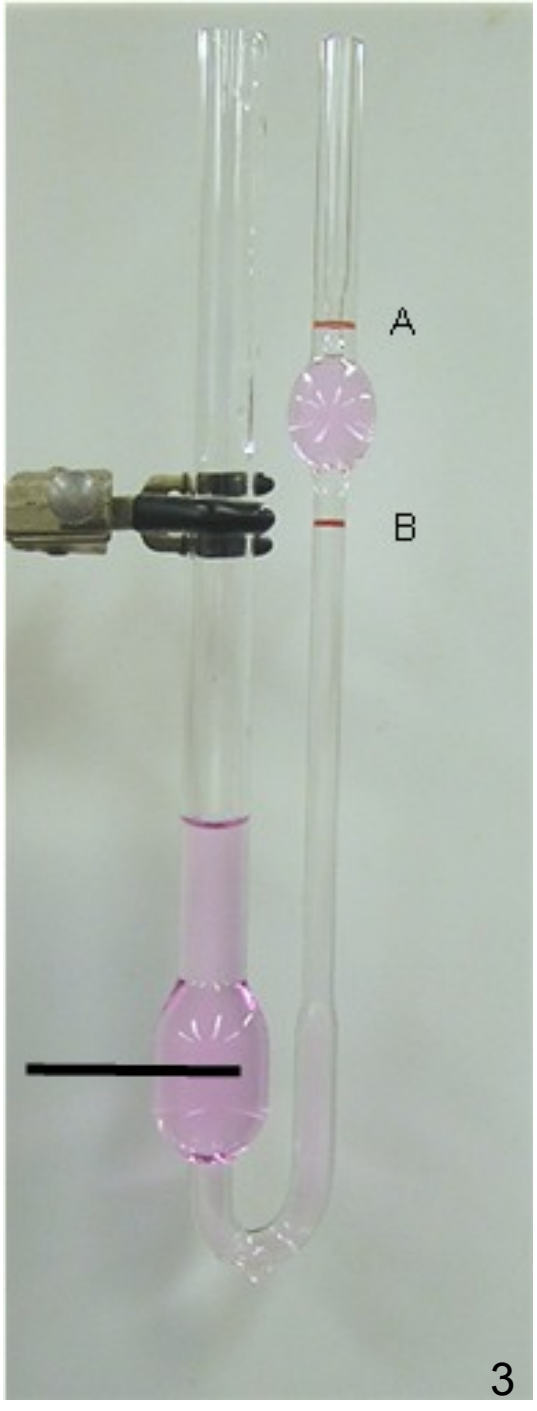
ρ = density of solution

r = radius of tube in constriction area

L = length of tube with constriction area

t = measured time

V = volume of liquid between A and B



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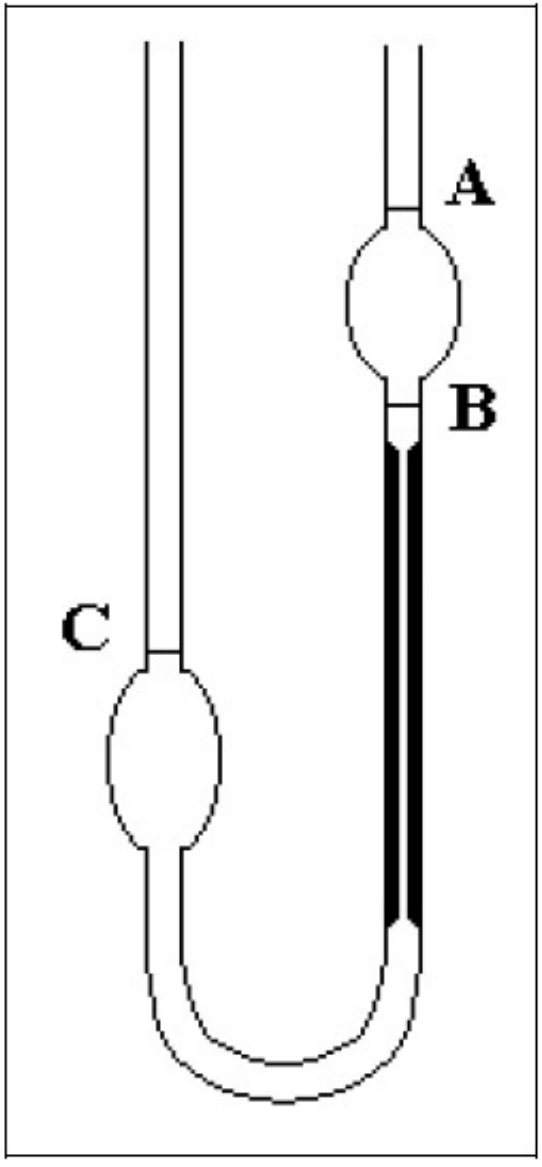

Ostwald Viscometer

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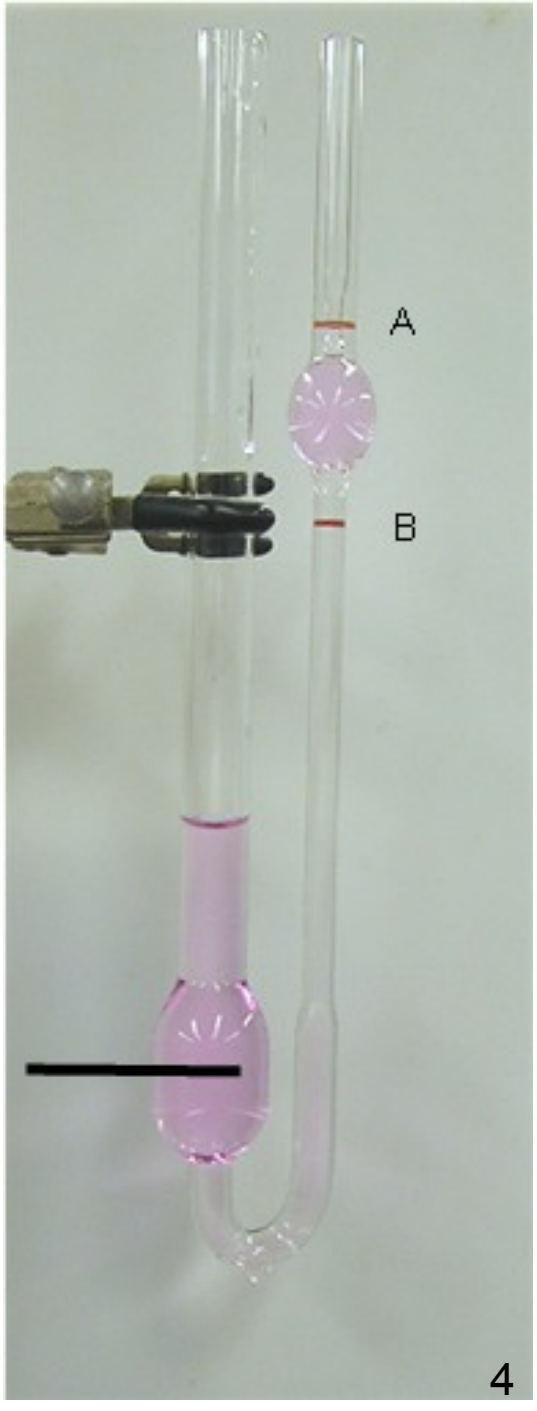
Apply suction at right tube until liquid level reaches A.

Measure the time *t* it takes for the liquid to flow back below level B, and calculate the **dynamic viscosity**:

$$\eta_S = C \cdot \rho \cdot t$$

Dynamic Viscosity = *Const* • Density • Time

The Ostwald Viscometer measures the Kinematic Viscosity (as time). Multiply this with the Solution Density to obtain the **Dynamic Viscosity**, which is the value we want.



Relative Viscosity

The **Relative Viscosity** is measured in comparison to a reference solution:

$$\eta_r = \frac{\eta_s}{\eta_w} = \frac{t_s \rho_s}{t_w \rho_w}$$

η_s = Dynamic viscosity of solution to measure

η_w = Dynamic viscosity of water as reference

t_s = Flow time for solution

t_w = Flow time for water

ρ_s = Density of solution to measure

ρ_w = Density of water as reference

η_s = Dynamic viscosity of solution

$[\eta]$ = Intrinsic viscosity = Viscosity at zero particle concentration

η_r = Relative viscosity = Viscosity relative to that of water

η_{sp} = Specific viscosity = $\eta_r - 1$

Specific Viscosity

$$\eta_{sp} = \frac{\eta_s - \eta_w}{\eta_w} = \eta_r - 1$$

η_{sp} = Specific viscosity of solution
η_r = Relative viscosity of solution
η_s = Dynamic viscosity of solution
η_w = Dynamic viscosity of water

The ***Relative Viscosity*** of pure water is **1**.

The ***Specific Viscosity*** of pure water is **0**.

η_s = Dynamic viscosity of solution
$[\eta]$ = Intrinsic viscosity = Viscosity at zero particle concentration
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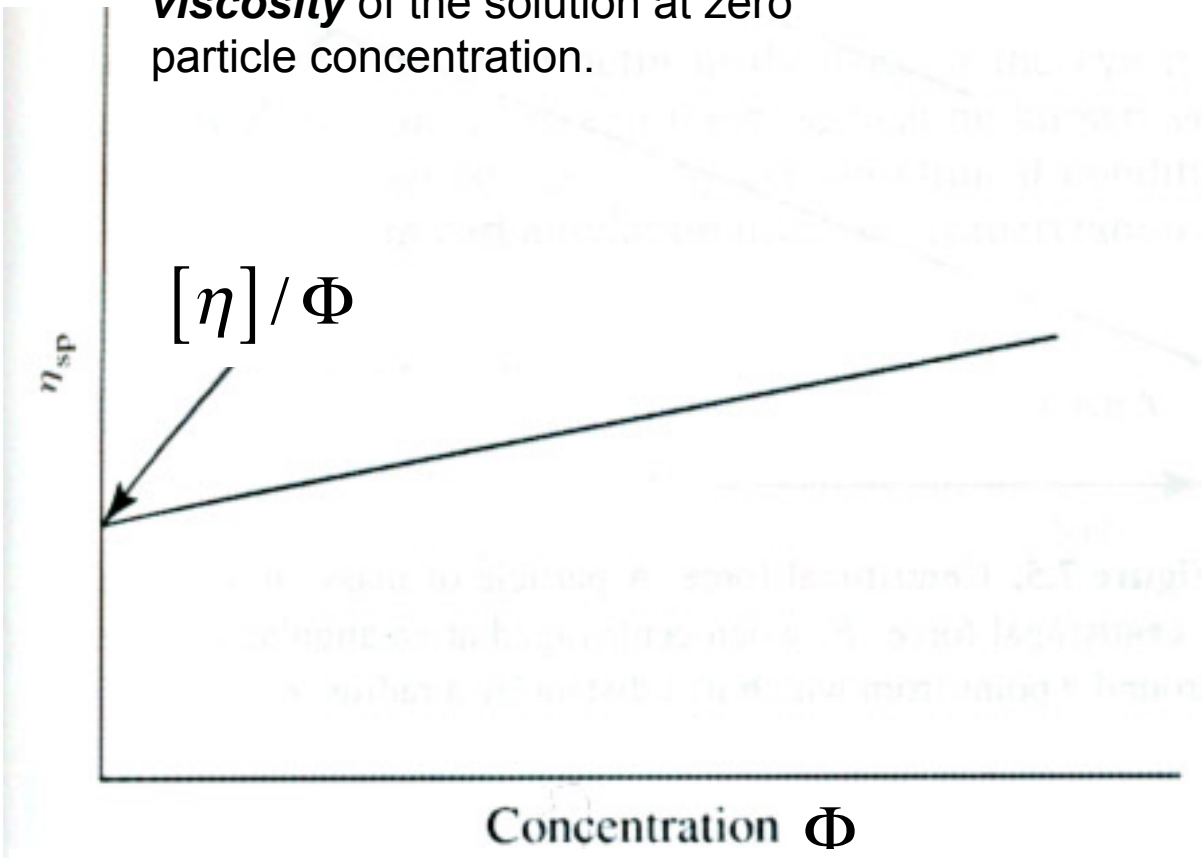
Intrinsic Viscosity $[\eta]$

The ***intrinsic viscosity*** of a particle-containing solution measures the contribution of the solute to the viscosity of a solution. It is the **slope of the *specific viscosity*** of the solution at zero particle concentration.

$$[\eta] = \lim_{\phi \to 0} \frac{\eta - \eta_w}{\eta_w \phi}$$

The ***intrinsic viscosity*** is a measure of a solute's contribution to the viscosity of a solution.



Measurement of intrinsic viscosity. The specific viscosity is measured at a range of concentrations of particles. The intrinsic viscosity [η] is the particle contribution to the specific viscosity (η_{sp}) at a particle concentration of zero.

$$\eta = [\eta] \cdot \phi \cdot \eta_s + \eta_s$$
$$= ([\eta] \cdot \phi + 1) \cdot \eta_s$$

For a particle-containing solution, the ***dynamic viscosity η*** is the ***specific viscosity η_{sp}*** of the solute plus the particle-concentration **Φ** dependent contribution from the **intrinsic viscosity** [***η***] of the particles

η = Dynamic viscosity (Solution may contain particles)
η_s = Dynamic viscosity of solute
$[\eta]$ = Intrinsic viscosity = Viscosity slope at zero particle concentration
η_r = Relative viscosity = Viscosity relative to that of water
η_{sp} = Specific viscosity = $\eta_r - 1$
Φ = *V*olume fraction of particles, or concentration of particles

Dependence of Viscosity on Temperature

Arrhenius type relationship for temperature-dependence of the dynamic viscosity:

$$\eta = A \cdot e^{\frac{B}{T}}$$

A = constant

B = constant

T = temperature [Kelvin]

In most cases, viscosity decreases at higher temperatures:
For example, honey becomes more liquid at higher temperatures.

Viscosity and Density of Water:

Temperature *[°C]*	Dynamic Viscosity *[N s/m²] x 10^{-3}*	Density *[g/l]*
0	1.787	1.000
5	1.519	1.000
10	1.307	1.000
20	1.002	0.998
30	0.798	0.996
40	0.653	0.992
50	0.547	0.989
60	0.467	0.983
70	0.404	0.978
80	0.355	0.973
90	0.315	0.966
100	0.282	0.972

η = Dynamic viscosity (solution may contain particles)

η_s = Dynamic viscosity of solution

$[\eta]$ = Intrinsic viscosity = Viscosity at zero particle concentration

η_r = Relative viscosity = Viscosity relative to that of water

η_{sp} = Specific viscosity = $\eta_r - 1$

- Refractive Index
- Viscosity
- Light Scattering
- Absorbance (280 nm)

Viscotec Tetra Detector Array

Tetra Detector Array/Analysis

Detector array consists of

- **Refractometer (refractive index RI)**
  - Concentration dn/dc [ml/g]
- **Viscometer (differential pressure DP)**
  - Intrinsic viscosity IV [dL/g] (deciliters/gram, defined by shape)
  - Hydrodynamic radius Rh [nm] (size)
- **Light Scattering (90° and 7°)**
  - mass [g/mole]
- **Absorption (280nm)**
  - Concentration dA/dc [ml/g]

Upon analysis

- **Absolute molecular weight**
- **Radius, Intrinsic viscosity (shape)**
- **% binding partners**
- **concentration**
- dn/dc

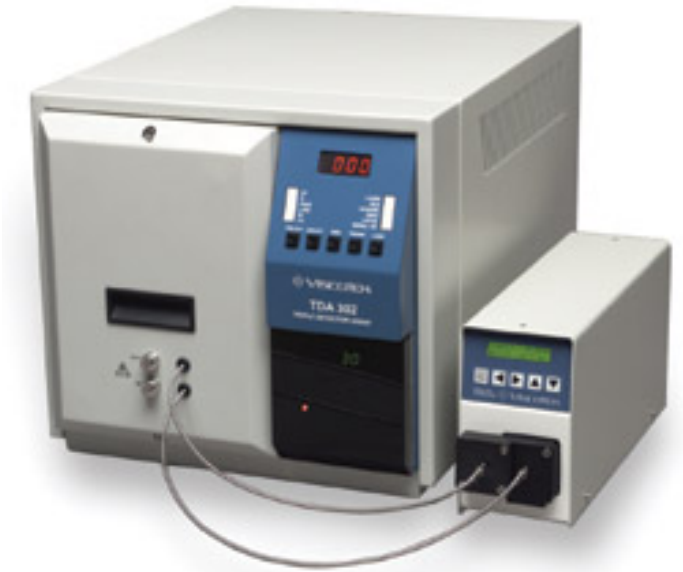
$$RI.sig \simeq C \cdot \frac{dn}{dc}$$

dn/dc is the refractive index increment. It quantifies how much the refractive index of a solution varies for a given increment in concentration c, expressed as g/mL

$$Visc.sig \simeq C \cdot IV$$

$$LS.sig \simeq C \cdot K_{opt} \cdot M_W \simeq C \cdot \left(\frac{dn}{dc}\right)^2 \cdot M_W$$

$$UV.sig \simeq C \cdot \frac{dA}{dc}$$



- Refractive Index
- Viscosity
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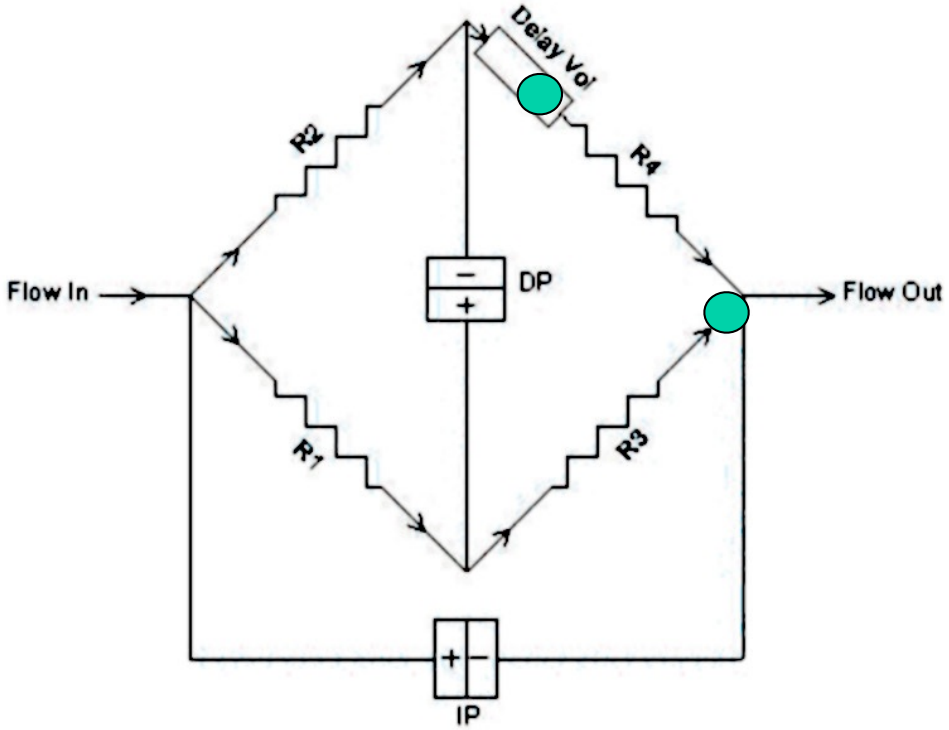
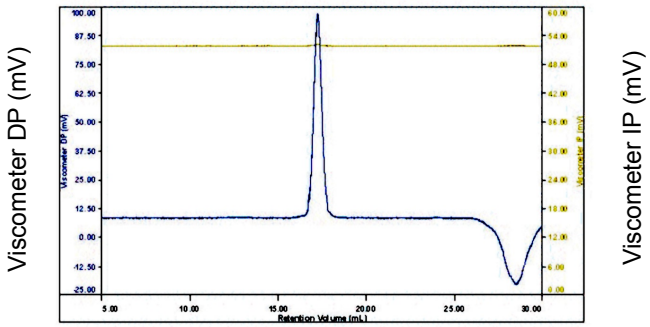
Differential Viscometer



- Four equal capillary resistances R1,R2,R3,R4.
- Delay Volume must be larger than elution volume of the column.
- DP measures the Difference in Pressure
- IP measures the Input Pressure

Viscosity Chromatogram of a polymer sample



η_s = Dynamic viscosity of solution

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η_{sp} = Specific viscosity = $\eta_r - 1$

Dependence of Viscosity on the Shape of the Molecule

Generally:
A solution with larger particles is more viscous.

But:
The detail is complicated and depends on the type of molecule.
For example:

For dsDNA of mass *M:*

$$[\eta] = \mathrm{e}^{0.665 \cdot \log(M) - 2.863} - 5$$

For random coil proteins of n residues dissolved in 6N guanidinium hydrochloride:

$$[\eta] = 0.716 \cdot n^{2/3}$$

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Dependence of Viscosity on Stress

Newtonian fluid: The viscosity is independent of the speed of the sample movement. $f = const$
Examples: water, air, and thin oil.

Frictional resistance of particle when passing through a Newtonian solvent:

$$F = f \cdot v$$

F = force of resitance to movement due to viscosity
f = frictional coefficient for particle in solution
(dependent on viscosity, and also shape and mass of particle)
v = velocity of particle in solution

Non-Newtonian fluid: The viscosity changes as a function of stress and shear in the liquid.

$$F = f(v) \cdot v$$

Examples:
Oobleck
(stiffens under stress)

$$\frac{f(v)}{f(0)} > 1$$

or Ketchup
(becomes liquid
under shear stress)

$$\frac{f(v)}{f(0)} < 1$$

A pool full of Oobleck
(mix cornstarch with water (2:1))

https://www.youtube.com/watch?v=yHIAcASsf6U

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http://edition.cnn.com/2017/03/27/tech/d3o-orange-gel/index.html

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Ketchup https://www.youtube.com/watch?v=KB43fM_ozKQ

Dependence of Viscosity on Stress

TED Ed

Lessons Worth Sharing

https://www.youtube.com/watch?v=KB43fM_ozKQ

LiquiGlide.com

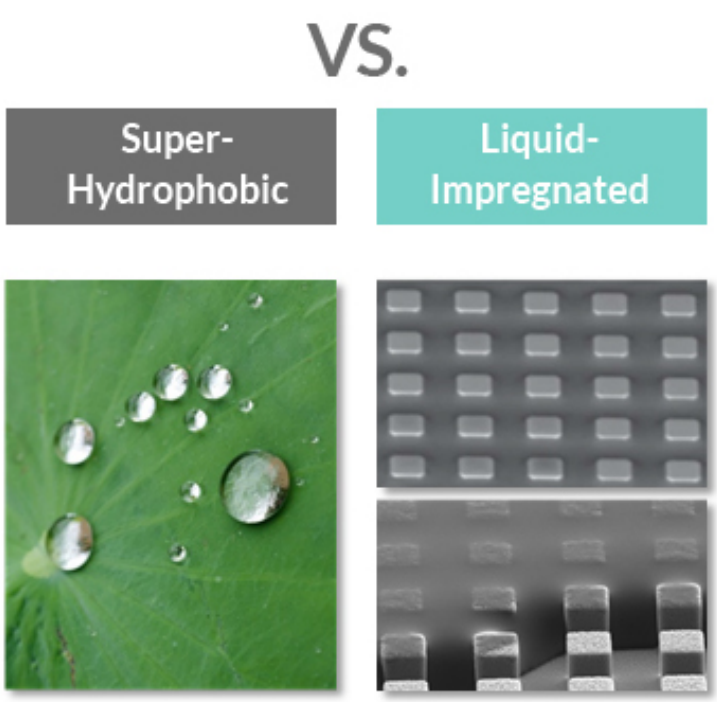
An MIT-based startup company.

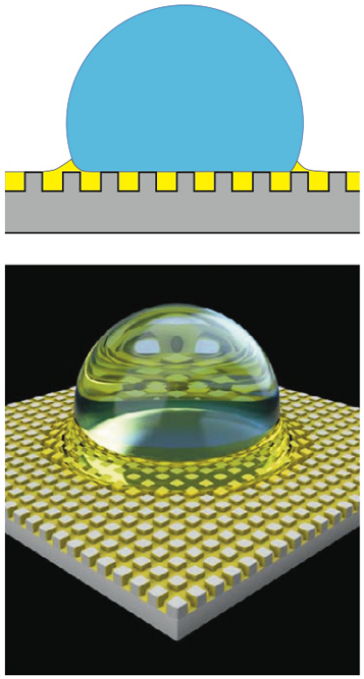
From their website:

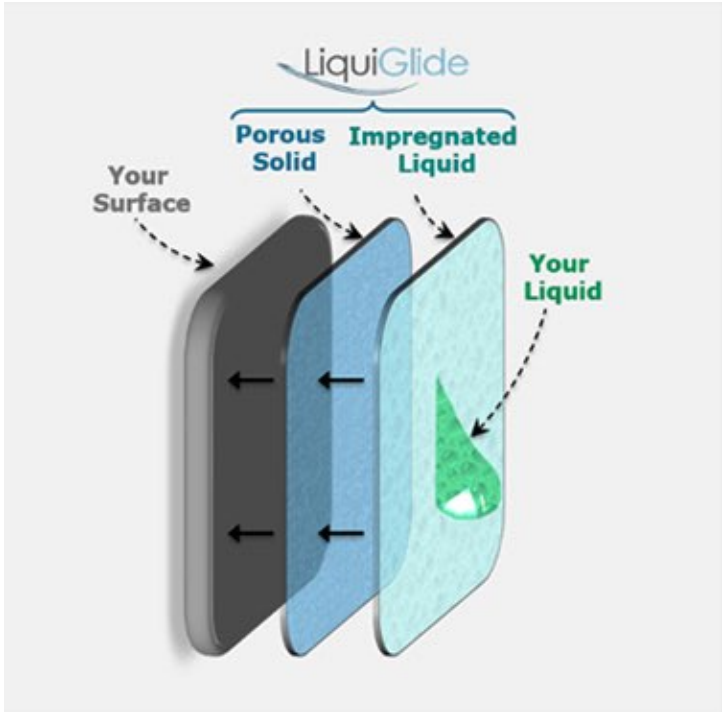
"LiquiGlide is the first and only permanently wet, slippery surface technology. There is no other durable solution that makes viscous liquids slide easily.

LiquiGlide is *NOT* a conventional super-hydrophobic surface technology. Do not be fooled by technologies that you have seen in the past that have similar visual effects. A conventional super-hydrophobic surface is like a lotus leaf; it is a highly textured surface which creates a cushion of air for the product to sit on.

LiquiGlide is a *permanently wet, liquid-impregnated surface* which is designed to be hyper slippery, with the product sitting directly on a layer of liquid. A liquid-impregnated surface is a multi-layer surface, consisting of a customized solid texture and a liquid. The highly textured solid surface is composed of a matrix of features spaced sufficiently close to stably contain the impregnating liquid that fills in the spaces between the features. The liquid is held in place within the texture, creating a permanently slippery, liquid surface. The product is actually sliding on our liquid layer, in a liquid-to-liquid interface."

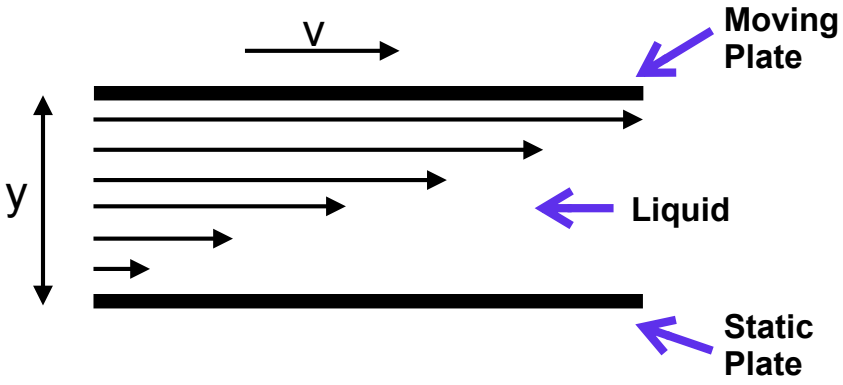


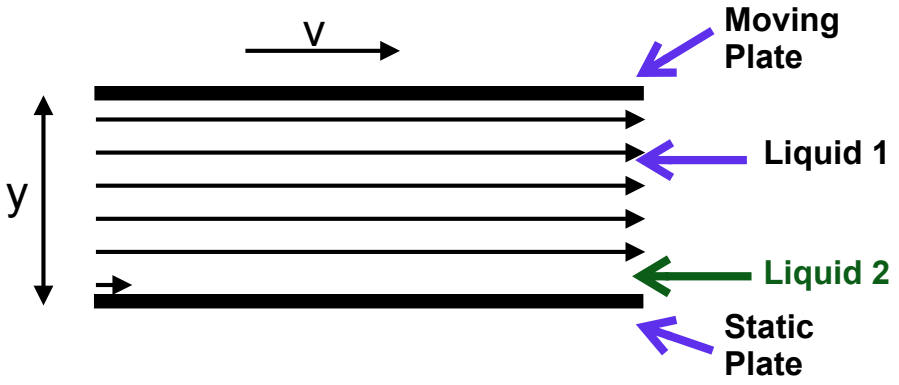


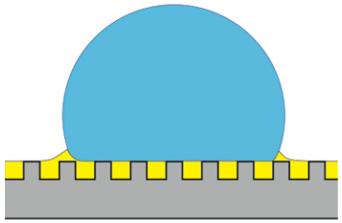


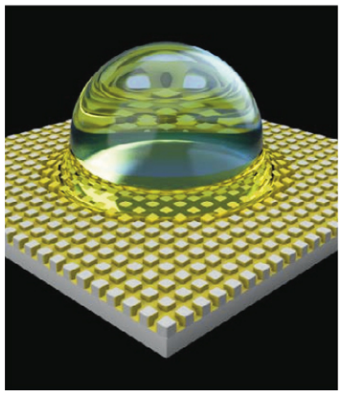
LiquiGlide.com

An MIT-based startup company.









LiquiGlide.com

From their website: An MIT-based startup company.

WHERE CAN I BUY LIQUIGLIDE COATINGS?

We do not sell coatings. We create coatings to meet the specific requirements of our clients and then license the coatings to them. If you are interested in contracting with us for development of a coating to meet your specific requirements, please contact us.

IS IT TOXIC? DOES THIS COATING USE ANY TYPE OF HARMFUL NANOTECHNOLOGY?

Nope! We can create coatings from all sorts of materials. For consumer products, such as condiments or body lotion we can use food materials. The coatings also do not involve nanotechnology. If you took a ketchup bottle with our coating and scraped off the coating with a knife, you could eat it and it would be completely harmless.

WON'T PEOPLE BUY FEWER BOTTLES IF THEY'RE ABLE TO GET EVERY LAST BIT OUT? ISN'T THIS BAD FOR THE COMPANIES?

How long has that almost-empty bottle been sitting in your fridge because it doesn't look empty? How much toothpaste do you use at the end of a tube's life vs. the beginning? How frustrated are you if a bottle of $200 beauty cream appears to have tons of cream still left, but you can't get it out? LiquiGlide makes dispensing product so easy that consumers actually tend to use it faster, as the individual dosage stays the same throughout the life of the product. This will increase sales for consumer brands, as it pushes consumers to an earlier repurchase point.

Flow Cytometry

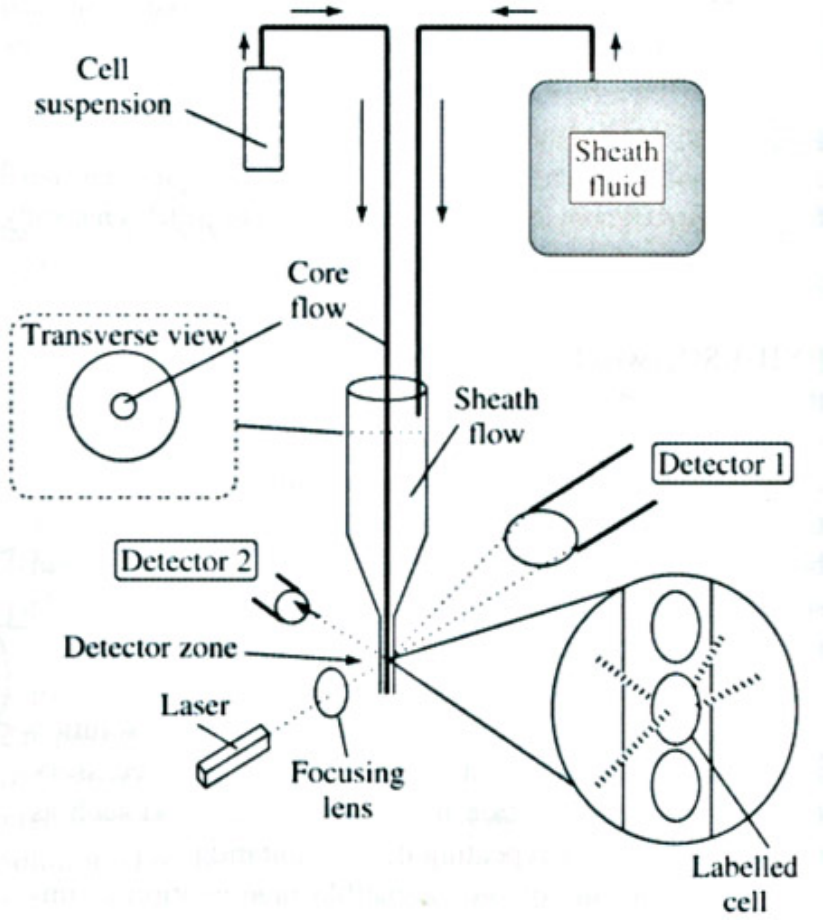
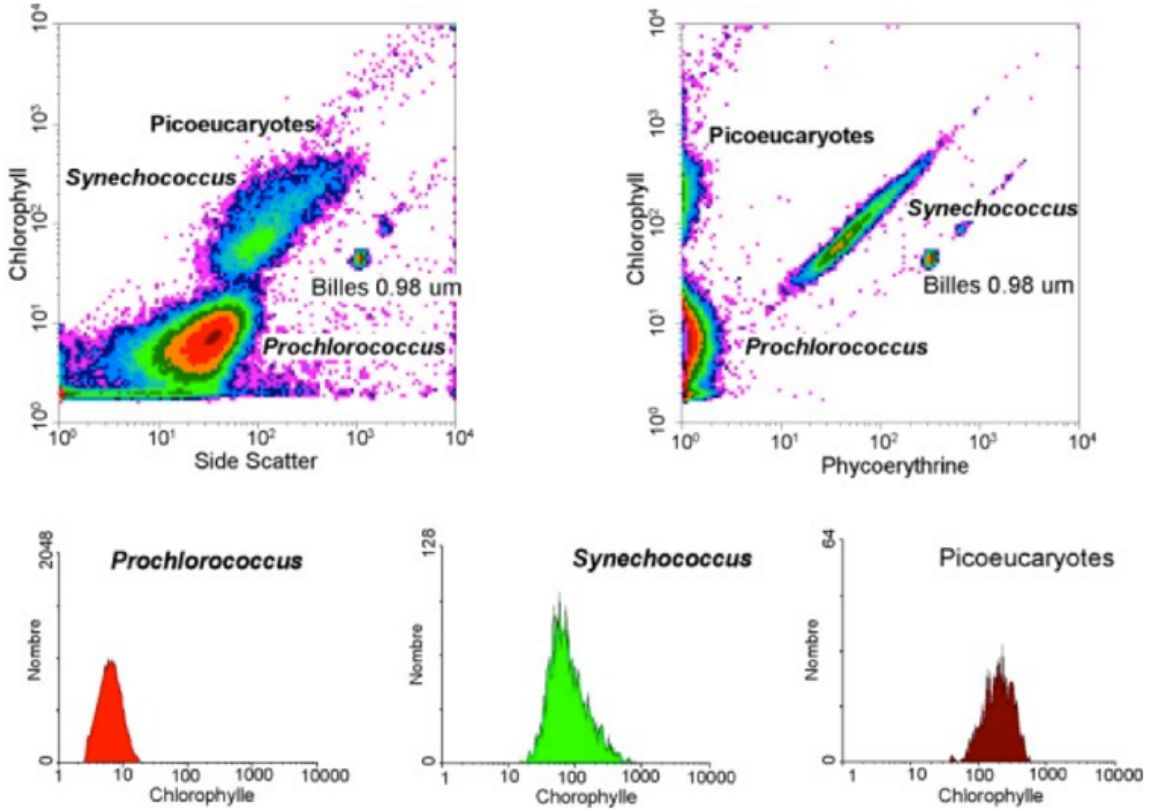


Figure 7.23. Outline design of a flow cytometer. Cells are carried in the core flow which directs them through the detector zone in single file. A transverse view is shown in the dashed box on left. The detector is an area where the beam from a laser is focused. Low angle scattered (forward-scattered) light is detected at detector 1, while right angle scattered and fluorescent light is detected at detector 2. Selective filters allow detection of specific emission wavelengths. The detail on right shows detection of a fluorescently-labelled cell as it passes through the detector.



Analysis of a marine sample of photosynthetic picoplankton by flow cytometry showing three different populations (*Prochlorococcus*, *Synechococcus,* and picoeukaryotes).

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

FACS – Fluorescence-Activated Cell Sorting

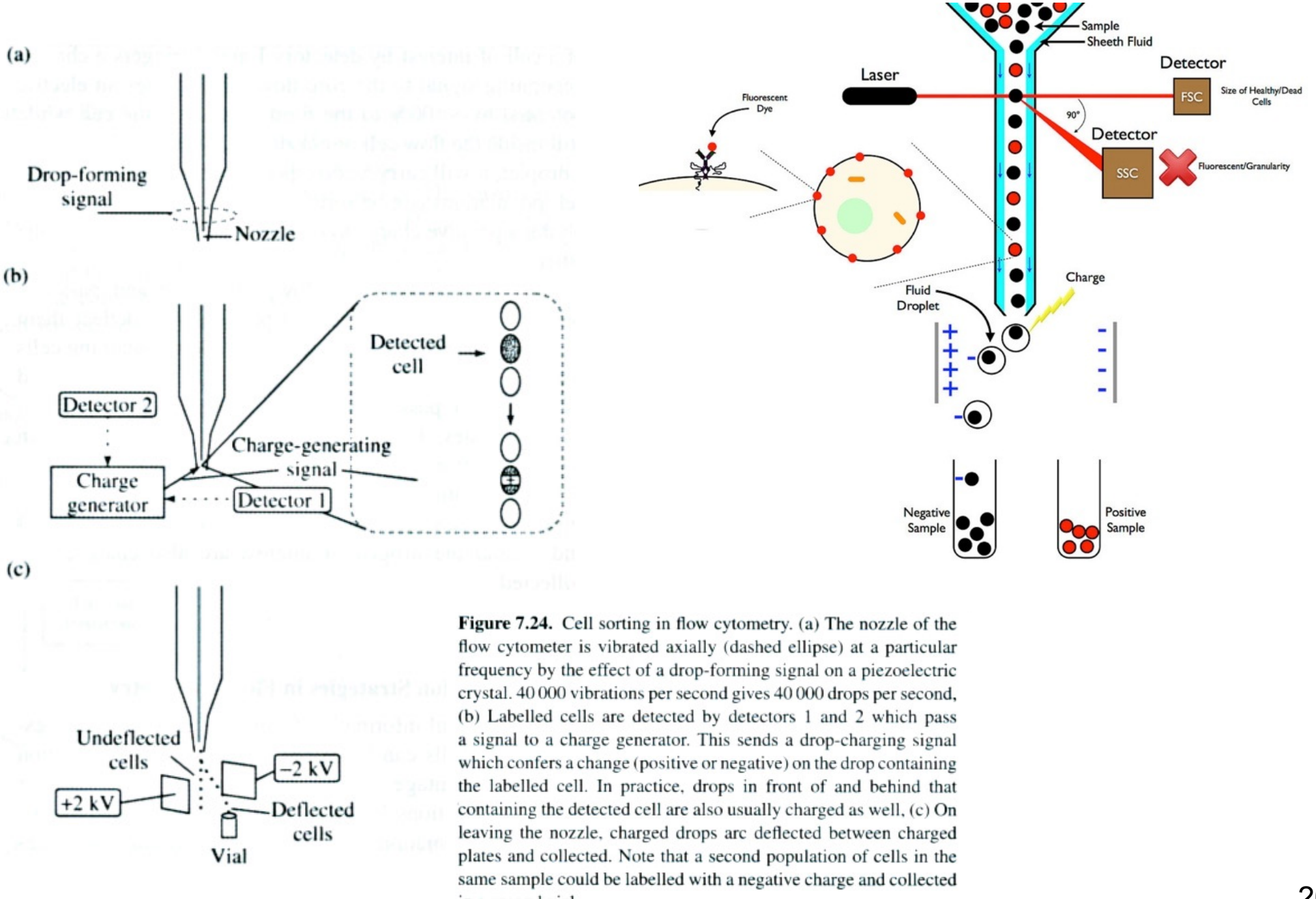
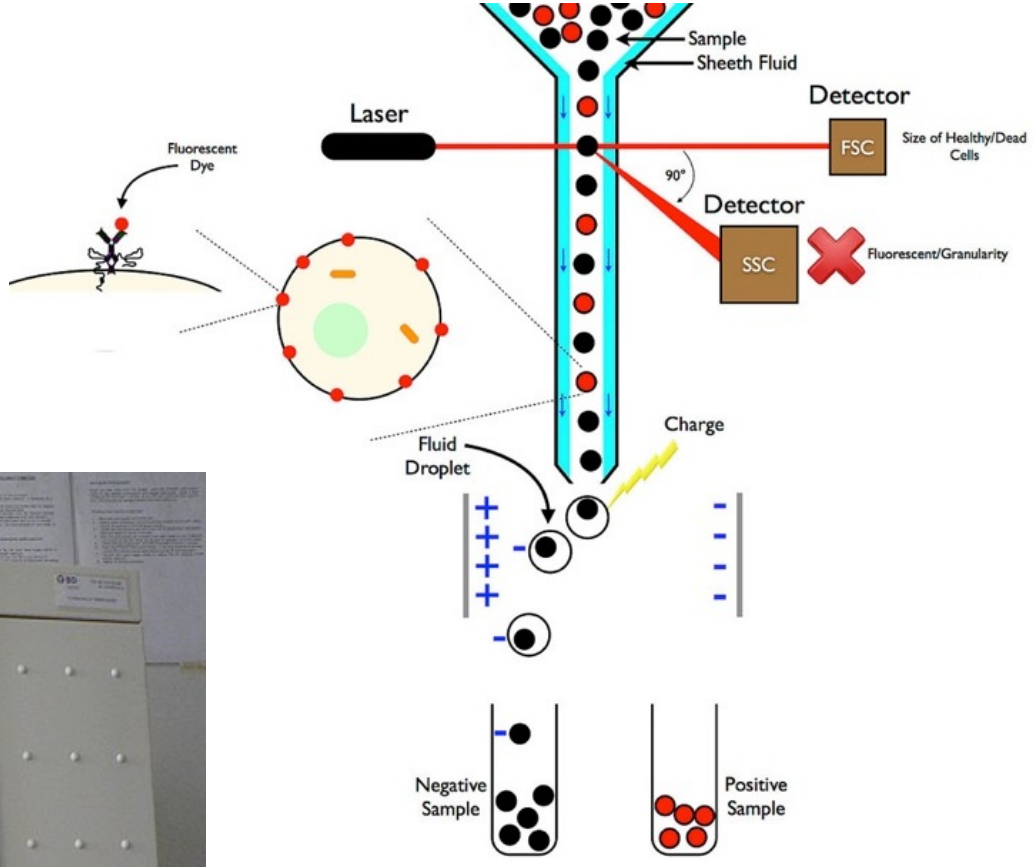


Figure 7.24. Cell sorting in flow cytometry. (a) The nozzle of the flow cytometer is vibrated axially (dashed ellipse) at a particular frequency by the effect of a drop-forming signal on a piezoelectric crystal. 40 000 vibrations per second gives 40 000 drops per second, (b) Labelled cells are detected by detectors 1 and 2 which pass a signal to a charge generator. This sends a drop-charging signal which confers a change (positive or negative) on the drop containing the labelled cell. In practice, drops in front of and behind that containing the detected cell are also usually charged as well, (c) On leaving the nozzle, charged drops are deflected between charged plates and collected. Note that a second population of cells in the same sample could be labelled with a negative charge and collected in a second vial.

FACS – Fluorescence-Activated Cell Sorting



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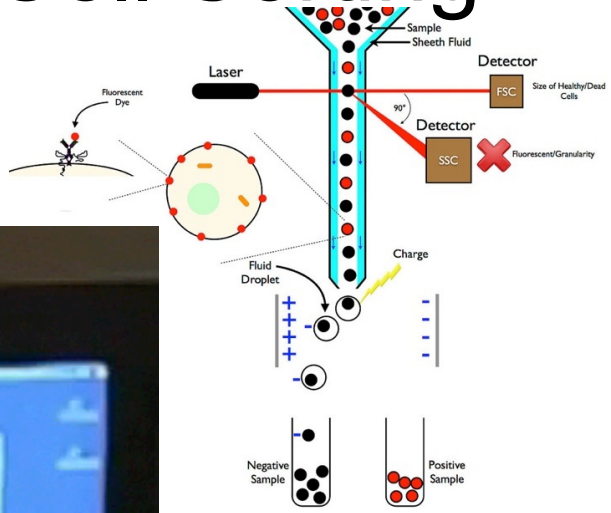

https://www.youtube.com/watch?v=nAfL4FXju1s