# Nanomaker

## Lab #7: Electrophoresis

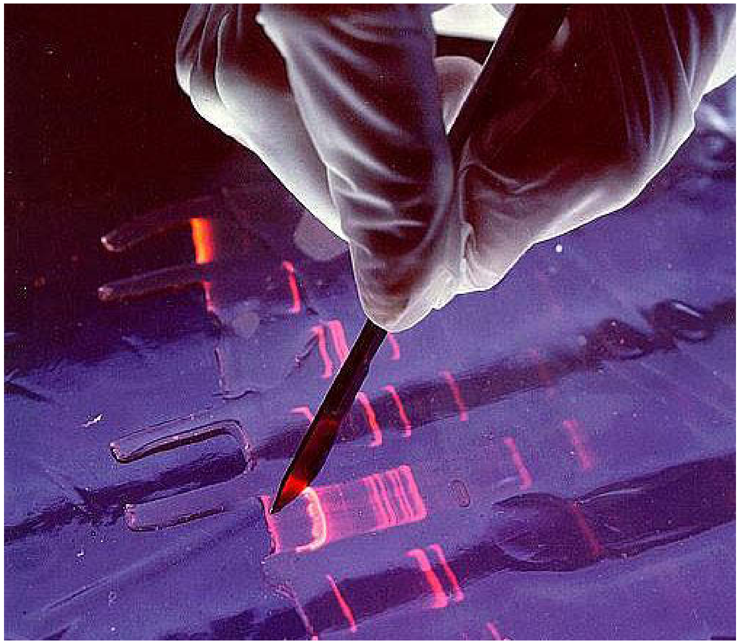


Photo courtesy of PNNL - Pacific Nortwest National Laboratory on Wikimedia Commons.

# Motion of Liquids/Particles

## Fick's/ Navier-Stokes/ Maxwell's Equations

## DNA Gel Electrophoresis

# How to Move Liquids/Particles?

- **Electroosmosis**
  - liquids with free charge move under external electric field where charged particles are stationary
- **Electrophoresis**
  - motion of charged particles due to an electric field
- **Dielectrophoresis**
  - motion of neutral particles due to a non-uniform electric field
- **Magnetophoresis**
  - motion of magnetic particles due to a magnetic field

# Electroosmosis

**The glass/water interface**
**(*electrokinetic effects*)**

- Silanol molecules (SiOH) on the glass surface react with free hydroxyl ions ($OH^-$) in the water, forming $Si(OH)_2^-$ and leaving the glass surface negatively charged.

- Free $H^+$ ions in the water are attracted by the negatively-charged surface and accumulate near it. The region containing this electrical potential gradient is called the *electric double layer*.

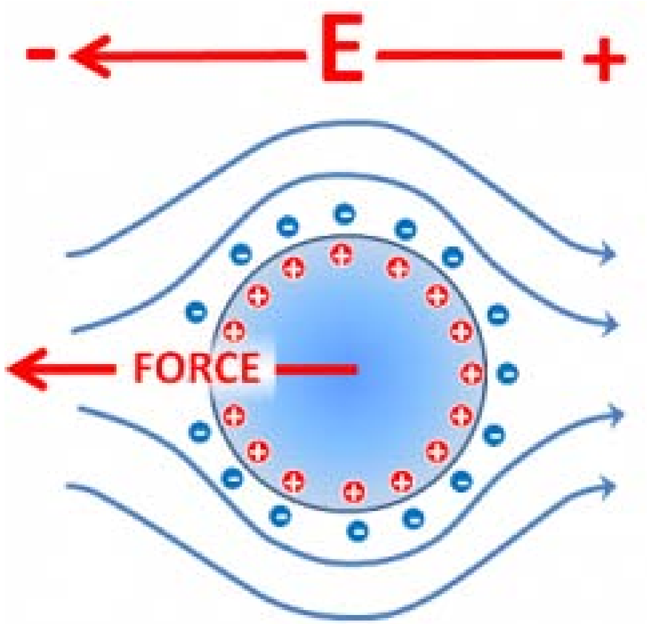
- The tail of the layer of $H^+$ ions is free to move under the influence of an applied E-field

## Example: Electroosmotic pump in glass capillary

Diagram of glass/water interface and electroosmosis pump in glass capillary removed due to copyright restrictions. Refer to: Daniel J. Laser's page on Electrokinetics and Electroosmosis Flow.

- Applying a voltage across a glass capillary will cause the $H^+$ ions at the interface to move to a lower potential
- The ions will drag the water in the center of the channel with them

# Electrophoresis

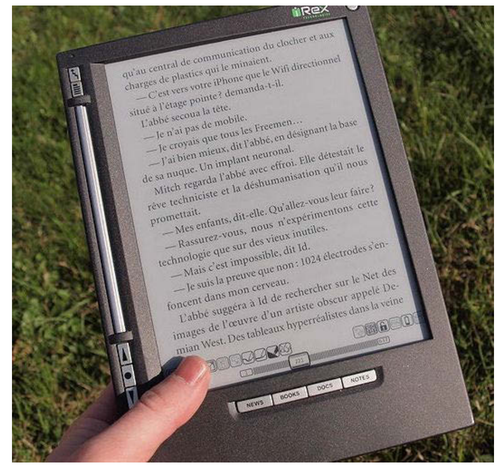



$$v = \mu E$$

μ = electrophoretic mobility and v = velocity



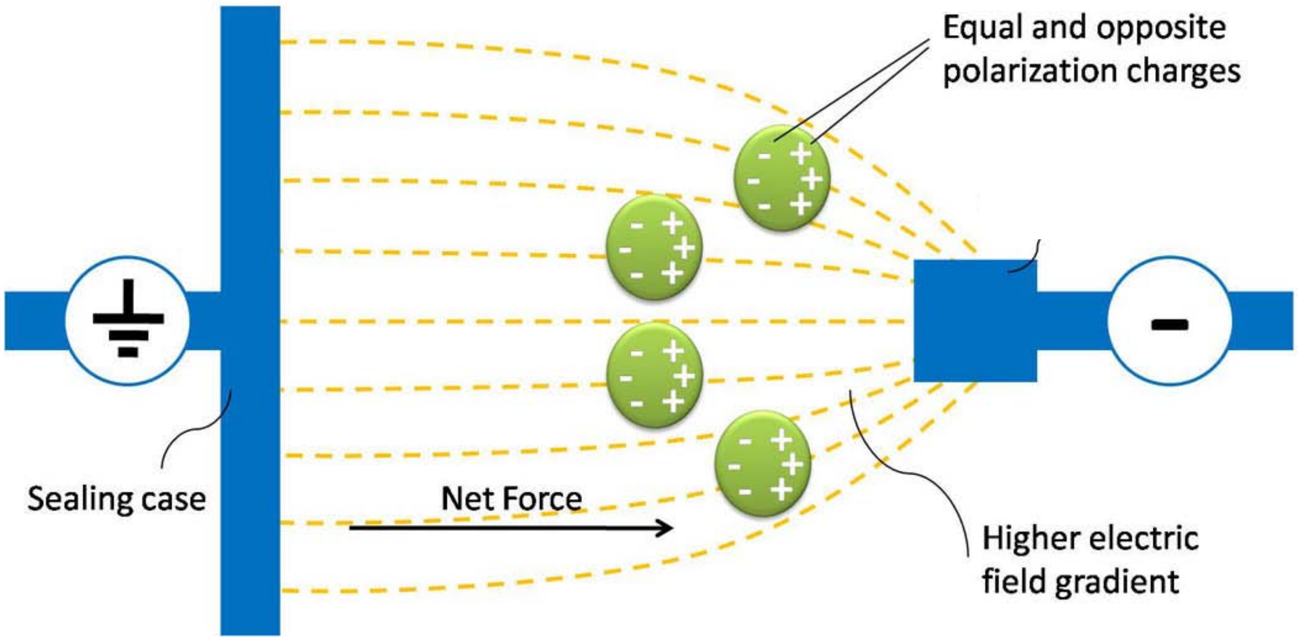
**electrophoretic displays**





- The motion of dispersed particles relative to a fluid under the influence of a spatially <u>uniform</u> electric field
- The particle velocity is the result of a balance between the electrostatic force and the friction force.

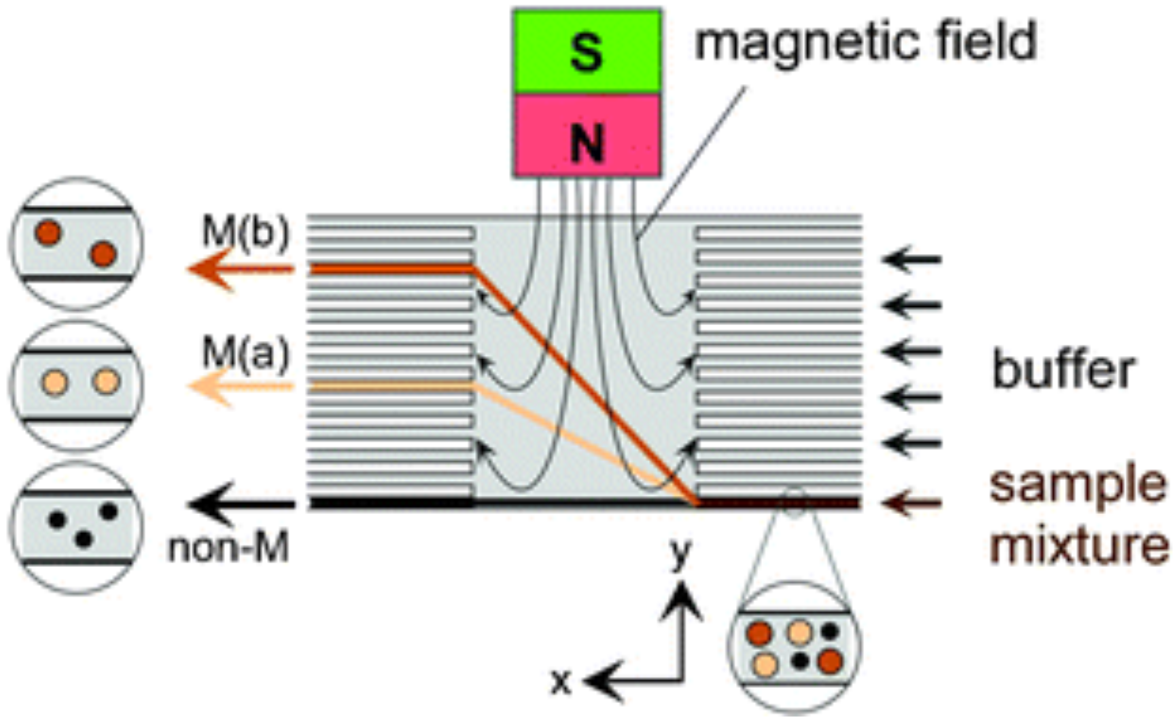
# Dielectrophoresis




From Wasisto, H.S., A. Waag, E. Peiner and E. Uhde. "Sensor monitors exposure to airborne nanoparticles." July 11, 2011. (https://spie.org/x48770.xml?ArticleID=x48770). Used with permission.

- Dielecrophoresis results in the polarization of a neutral particle (dipole).
- A force is exerted on a dielectric particle when it is subjected to a non-uniform electric field. It does not require the particle to be charged.
- The strength of the force depends strongly on the medium and particles' electrical properties, on the particles' shape and size, as well as on the frequency of the electric field.

# Magnetophoresis



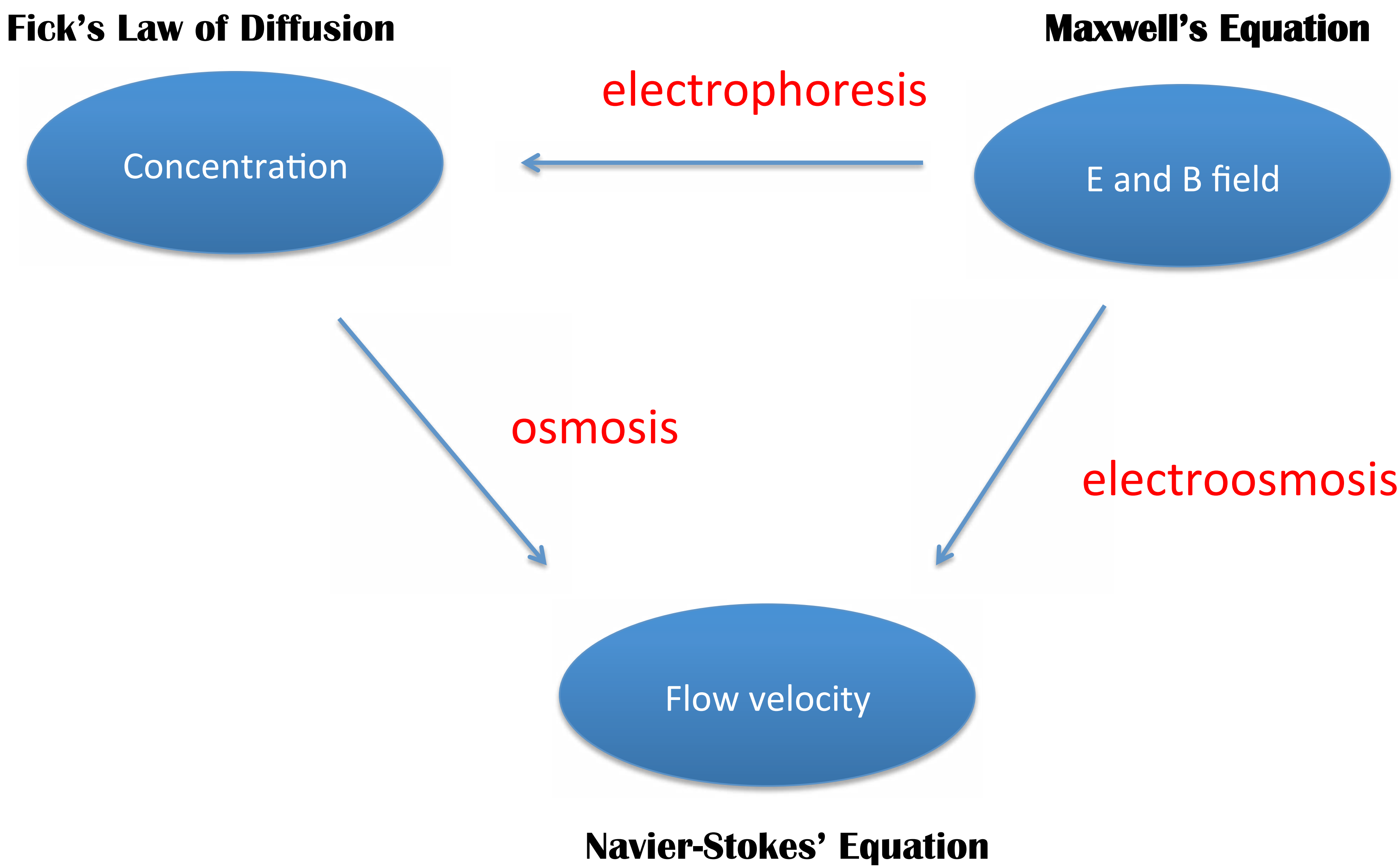



- Magnetophoresis is the motion of dispersed magnetic particles relative to a fluid under the influence of a magnetic field.
- Continuous sorting of cells loaded with magnetic nanoparticles in a microfluidic device.

# Motion of Liquids/Particles

# Fick's/ Navier-Stokes/ Maxwell's Equations

# DNA Gel Electrophoresis


Fick's Law of Diffusion
Maxwell's Equation
electrophoresis
Concentration
E and B field
osmosis
electroosmosis
Flow velocity
Navier-Stokes' Equation

# Fick’s Law of Diffusion

First Law: $$J = \quad D\frac{\partial \phi}{\partial x}$$

Second Law: $$\frac{\partial \phi}{\partial t} = D\frac{\partial^2 \phi}{\partial x^2}$$


$$L = 2\sqrt{Dt}$$

where *L* is the diffusion length, *t* is the time, *D* is the molecular diffusion coefficient. The diffusion coefficient scales roughly with the inverse of the size of the molecule and also depends to some extent on the shape of the molecule. It also increases with temperature and decrease with pressure.

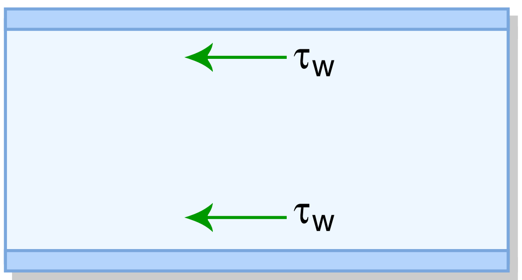
# Navier-Stokes' Equation

The Navier-Stokes' equation for incompressible flow:

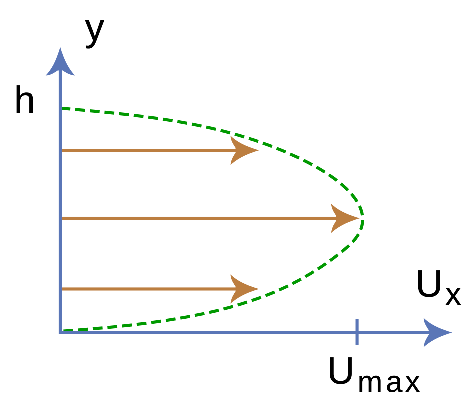
$$\rho \frac{dU}{dt} = \eta \nabla^2 U - \nabla P$$

$U$ = velocity
$P$ = pressure
$t$ = time
$\rho$ = fluid density ($10^3$ kg/m3 for water)
$\eta$ = Viscosity ($10^{-3}$ Pa-s for water)

High P




Low P



# Maxwell's Equation

*Maxwell's equations* consist of

- Gauss's law for the electric field
- Gauss's law for the magnetic field
- Faraday's law
- Ampere's law

$$\Phi_E = \oint E \cdot dA = \frac{Q}{\varepsilon_0} \qquad \Phi_B = \oint B \cdot dA = 0$$

$$\oint E \cdot dl = -\frac{d\Phi_B}{dt} \qquad \oint B \cdot dl = \mu_0 (\varepsilon_0 \frac{d\Phi_E}{dt} + I_{encl})$$

# Motion of Liquids/Particles

# Fick's/ Navier-Stokes/ Maxwell's Equations

# DNA Gel Electrophoresis

# DNA Gel Electrophoresis

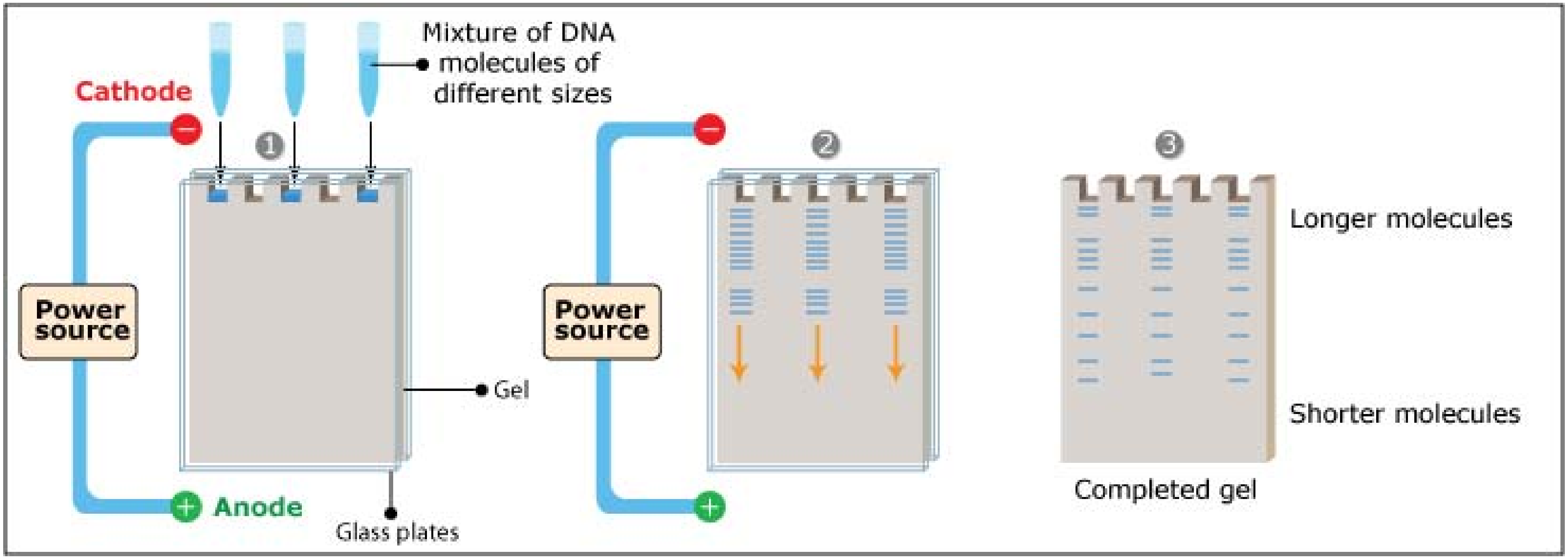



Image by MIT OpenCourseWare.

- A method of separating DNA in a gelatin-like material using an electrical field
  - DNA is negatively charged
  - Size of DNA fragment affects how far it travels

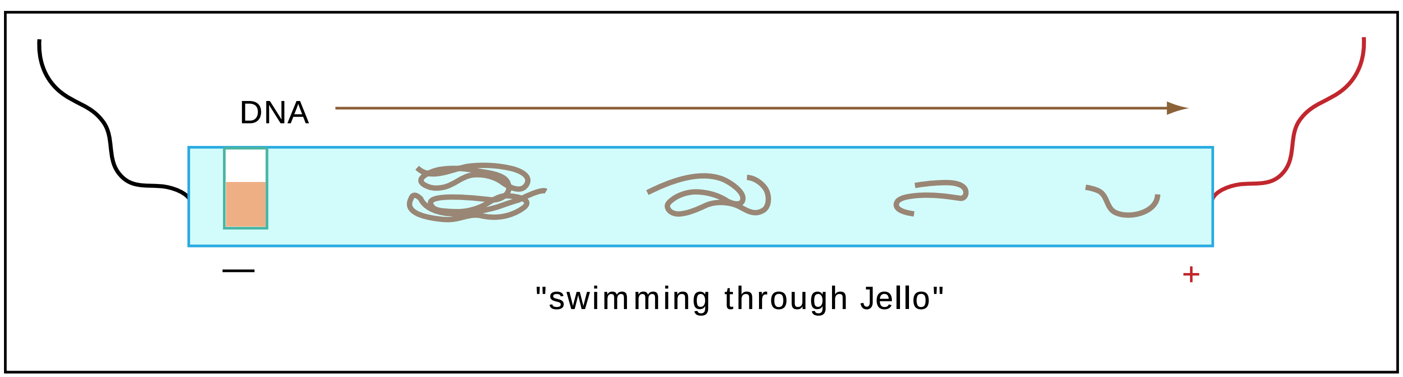



Image by MIT OpenCourseWare.

# DNA Gel Electrophoresis

- **Stage 1**:
  - Cells are broken down to release DNA

- **Step 2:**
  - The DNA is cut into fragments using **restriction enzymes**. Each restriction enzyme cuts DNA at a specific base sequence.

- **Stage 3:**
  - Fragments are separated on the basis of size using a process called <u>gel electrophoresis.</u>

- **Stage 4:**
  - DNA fragments are injected into wells and an electric current is applied along the gel.
  - DNA is negatively charged so it is attracted to the positive end of the gel.
  - The shorter DNA fragments move faster than the longer fragments. DNA is separated on basis of size.

- **Stage 5:**
  - A radioactive material is added which combines with the DNA fragments to produce a fluorescent image.
  - A photographic copy of the DNA bands is obtained.

# DNA Gel Electrophoresis

Process diagram of gel electrophoresis removed due to copyright restrictions.

# DNA Gel Electrophoresis

Colin Pitchfork:
the first criminal caught based on DNA fingerprinting evidence. He was arrested in 1986 for the rape and murder of two girls and was sentenced in 1988.

O.J. Simpson:
cleared of a double murder charge in 1994 which relied heavily on DNA evidence. This case highlighted lab difficulties.

# Conclusions