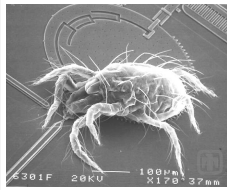
Introduction to nanoscience and nanotechnology

The Scale of Things – Nanometers and More

Things Natural

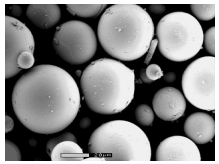


Dust mite

200 μm

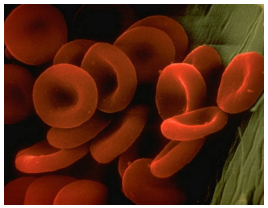
Ant
~ 5 mm

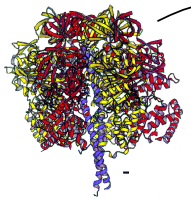
Human hair
~ 60-120 μm wide



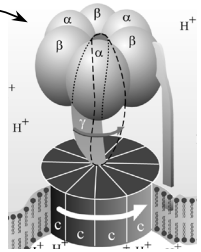
Fly ash
~ 10-20 μm

Red blood cells
(~7-8 μm)

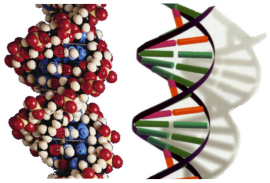




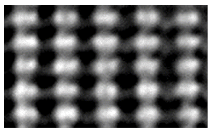
~10 nm diameter



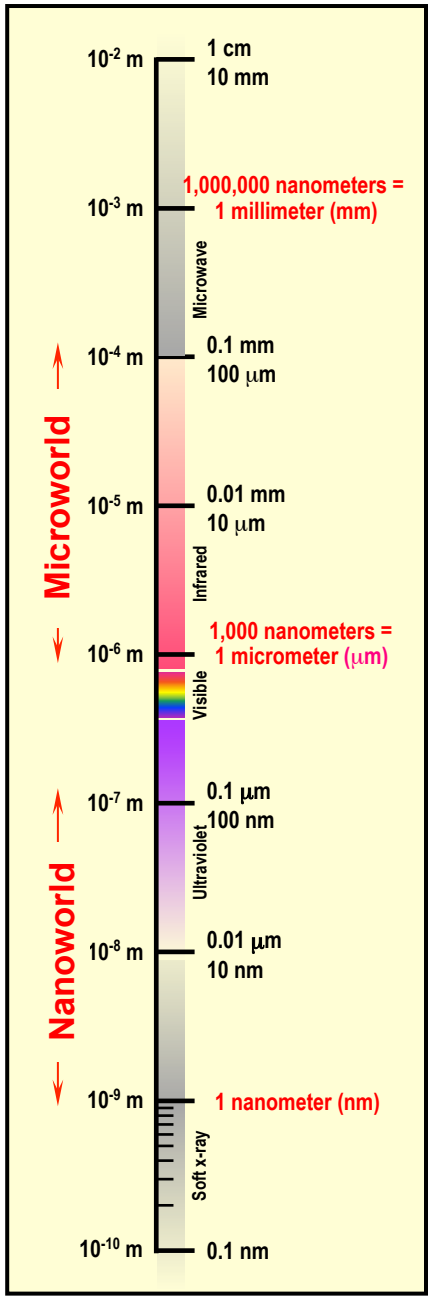
ATP synthase



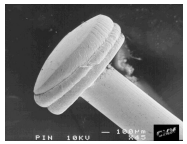
DNA
~2-1/2 nm diameter



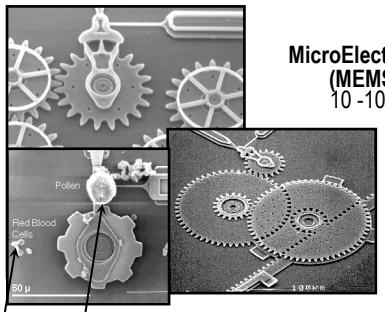
Atoms of silicon
spacing 0.078 nm



Things Manmade

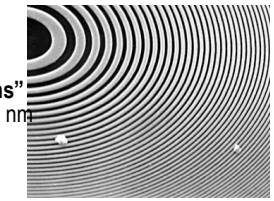


Head of a pin
1-2 mm

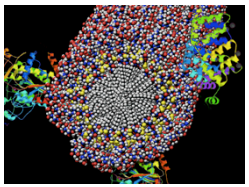


MicroElectroMechanical (MEMS) devices
10 -100 μm wide

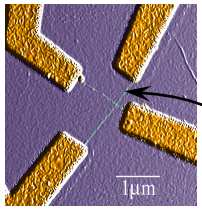
Pollen grain
Red blood cells



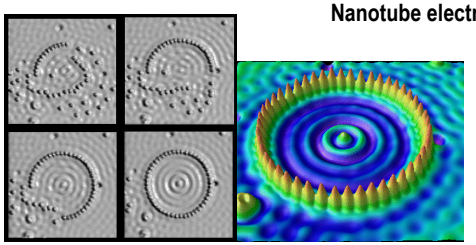
Zone plate x-ray "lens"
Outer ring spacing ~35 nm



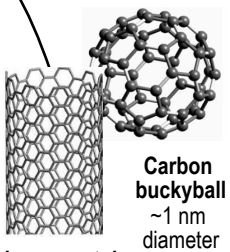
Self-assembled,
Nature-inspired structure
Many 10s of nm



Nanotube electrode



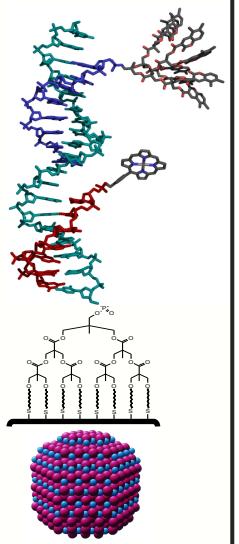
Quantum corral of 48 iron atoms on copper surface positioned one at a time with an STM tip
Corral diameter 14 nm



Carbon buckyball
~1 nm diameter

Carbon nanotube
~1.3 nm diameter

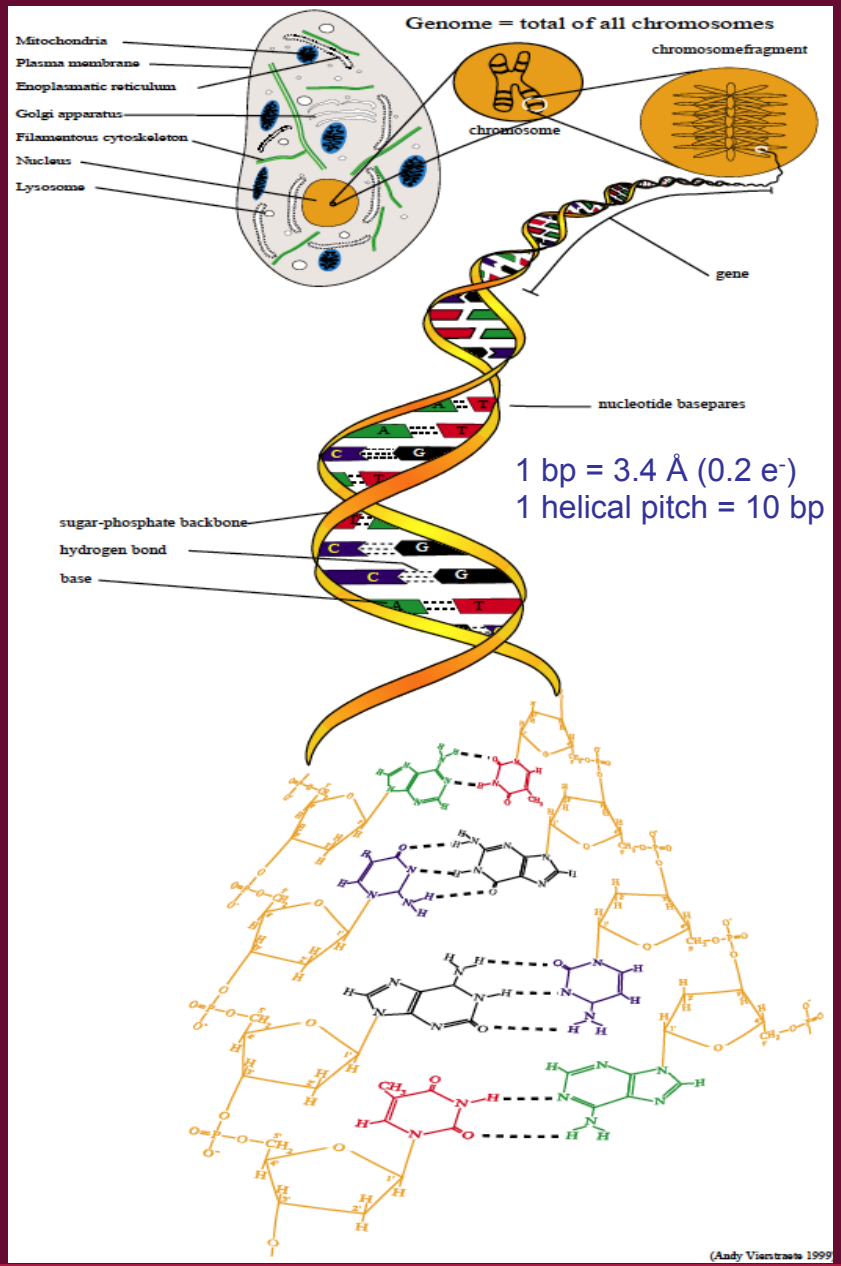
The Challenge

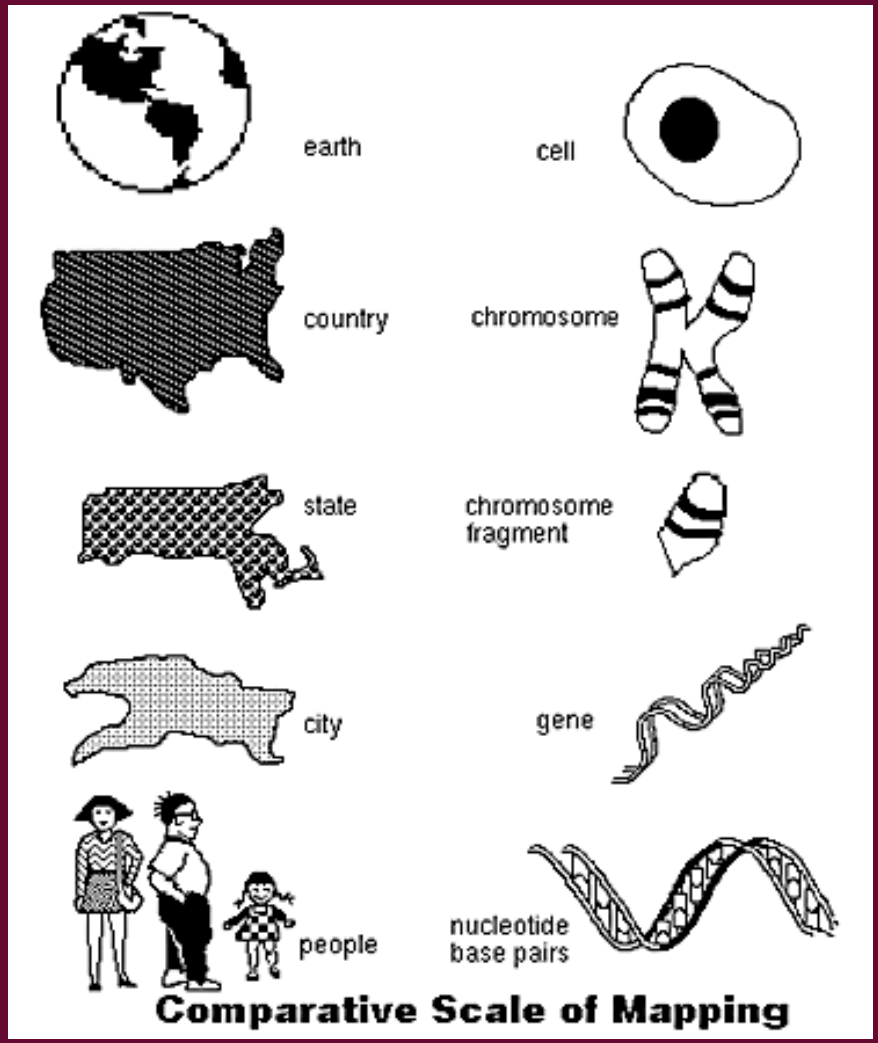


Fabricate and combine nanoscale building blocks to make useful devices, e.g., a photosynthetic reaction center with integral semiconductor storage.

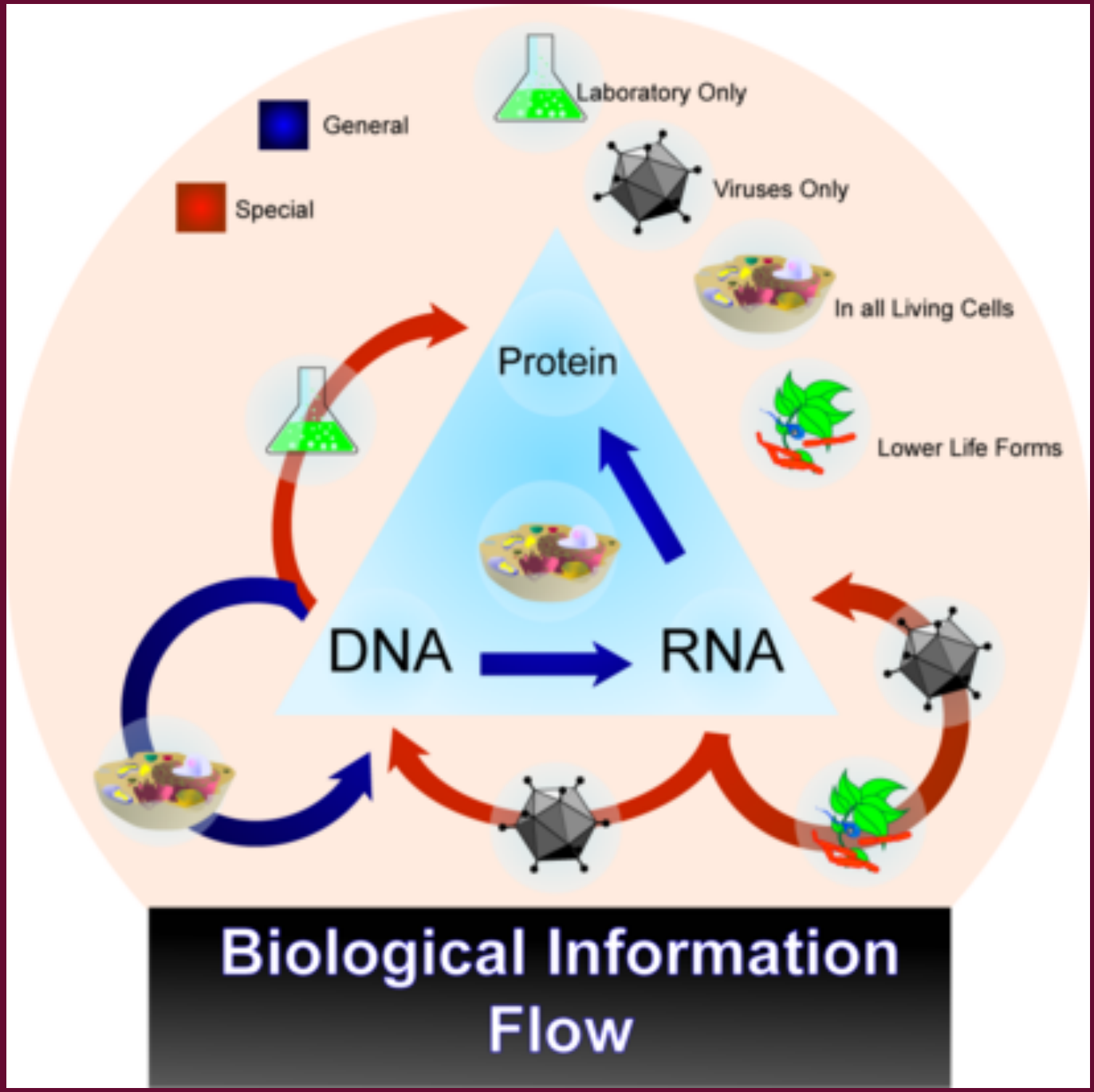
Office of Basic Energy Sciences
Office of Science, U.S. DOE
Version 05-26-06, pmd

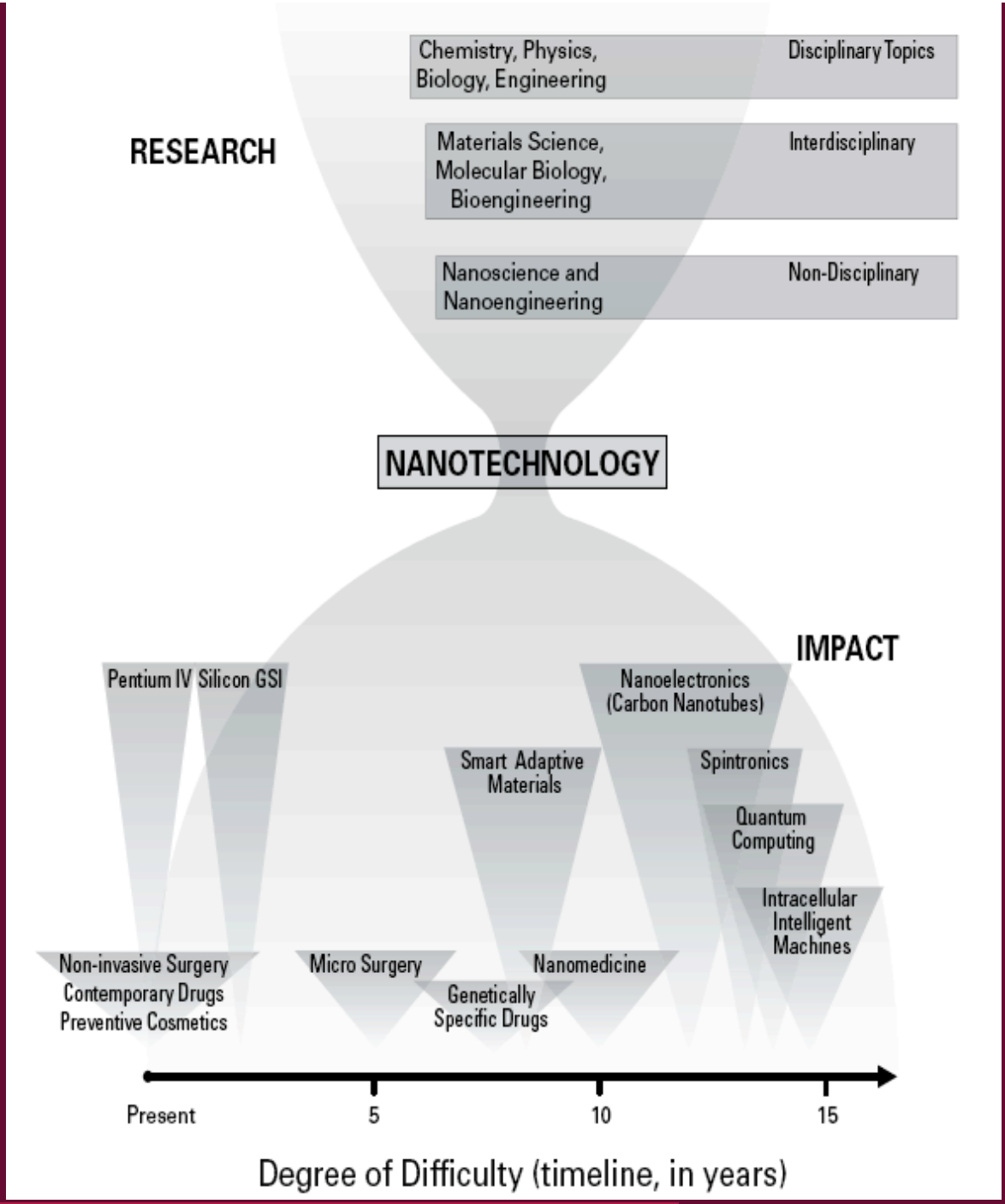
Cell and Molecules



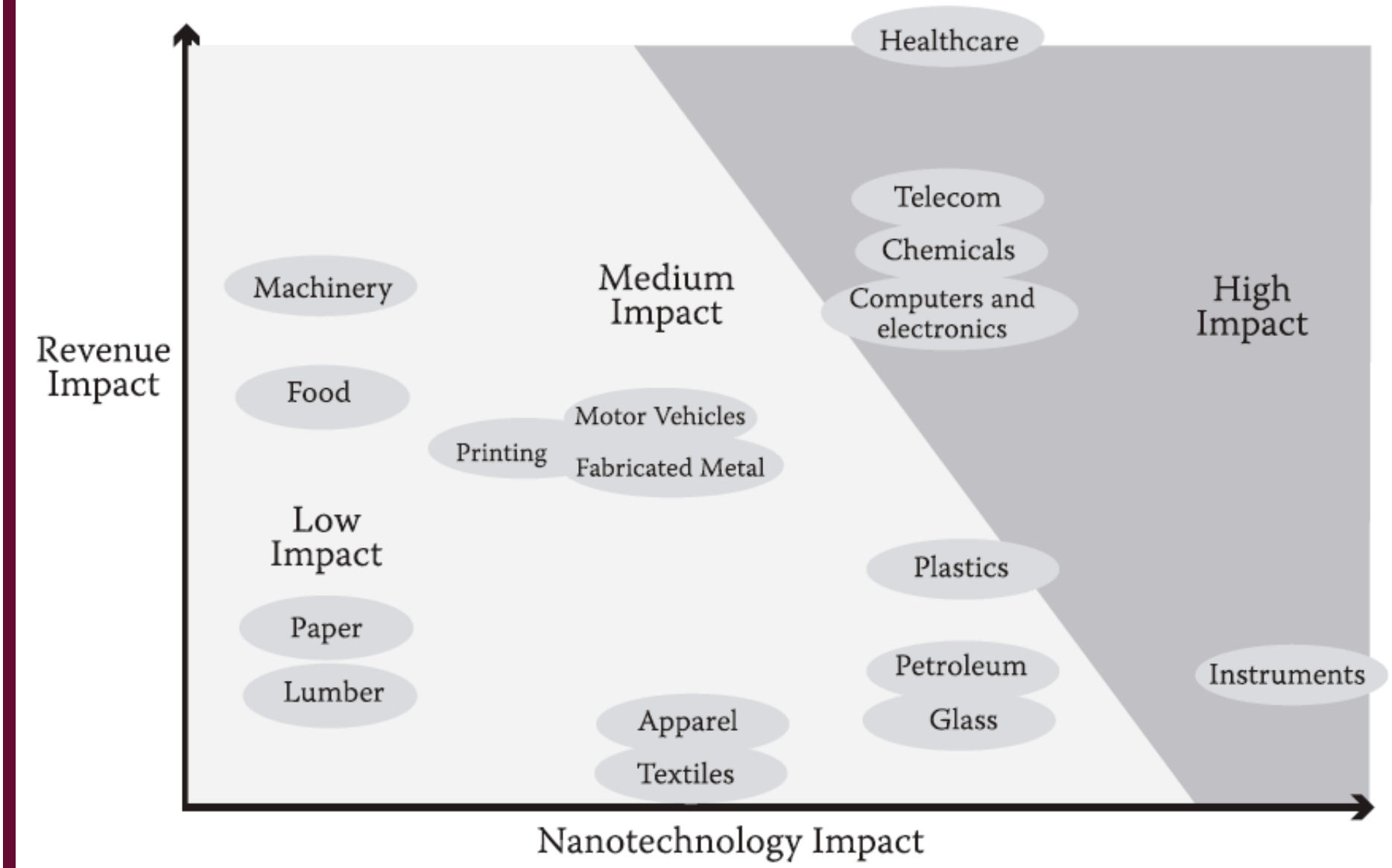


http://accessexcellence.org/RC/VL/GG/comparative.html


General
Special
Laboratory Only
Viruses Only
In all Living Cells
Lower Life Forms
Protein
DNA
RNA
Biological Information Flow


Chemistry, Physics, Biology, Engineering
Disciplinary Topics
RESEARCH
Materials Science, Molecular Biology, Bioengineering
Interdisciplinary
Nanoscience and Nanoengineering
Non-Disciplinary
NANOTECHNOLOGY
IMPACT
Pentium IV Silicon GSI
Nanoelectronics (Carbon Nanotubes)
Smart Adaptive Materials
Spintronics
Quantum Computing
Intracellular Intelligent Machines
Non-invasive Surgery
Contemporary Drugs
Preventive Cosmetics
Micro Surgery
Nanomedicine
Genetically Specific Drugs
Present
5
10
15
Degree of Difficulty (timeline, in years)

Nanotechnology's Probable Business Impact in 2007

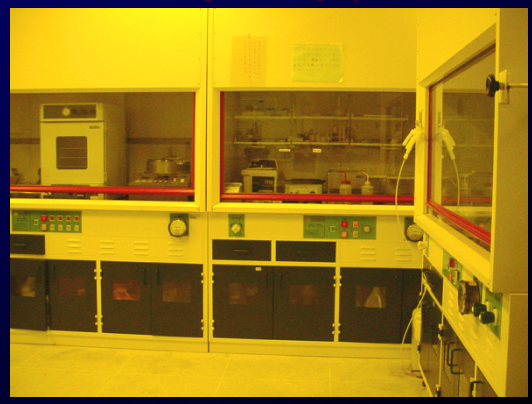


Device fabrication facilities in a class-1000 cleanroom

E-beam writer

Laser writer

Photolithography yellow room



ICP Etcher

Evaporators

SEM, AFM, RIE, …

Dual beam FIB

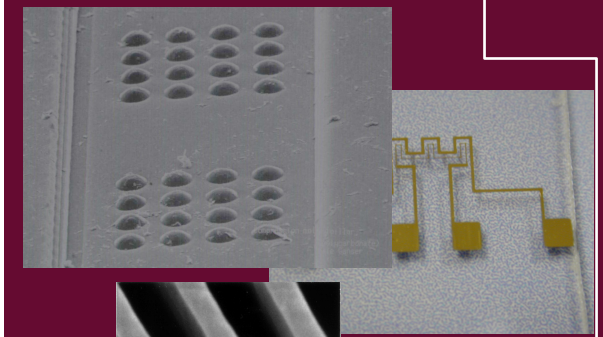
Scanning probe microscopy

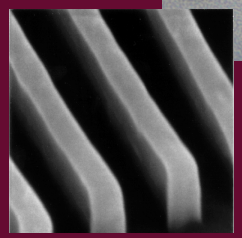
3D-FESEM

Manufacturing and prototyping

Fabrication methods

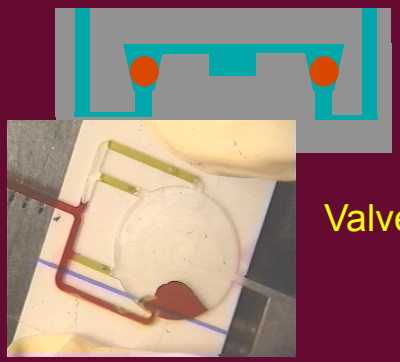
Molding, embossing, NanoImprinting



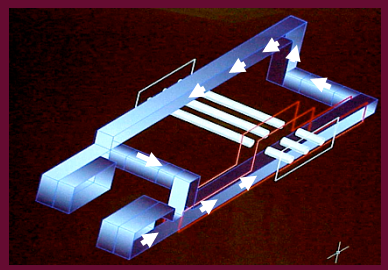


NIL Mask, 70 nm

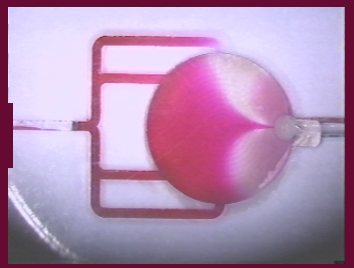
Device components



Valves

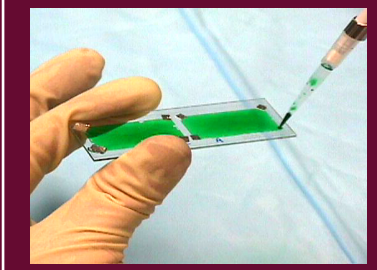


Pumps

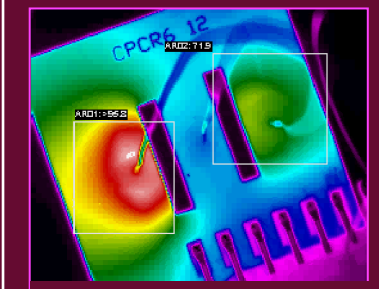


Mixers

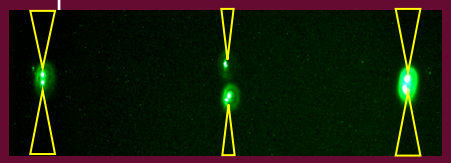
Assays



Channel hyb

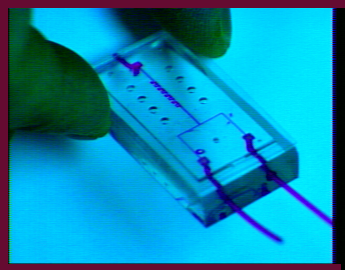


Amplification - PCR

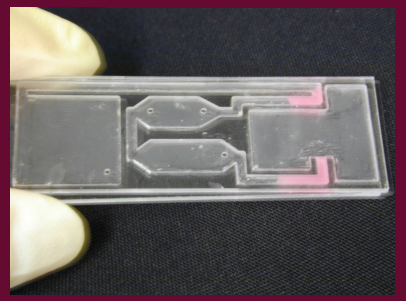


Cell and DNA capture

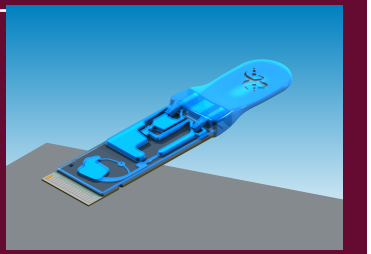
Integrated solutions



Multi-layer devices



Multi-functional cartridges



Amplification-
Detection
On Chip

Navier-Stokes Equation for Newtonian fluid:

$$\rho \left[\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{v} \right] = \eta \nabla^2 \mathbf{v} - \nabla p.$$

$$Re = \frac{\rho v_s^2 / L}{\mu v_s / L^2} = \frac{\rho v_s L}{\mu} = \frac{v_s L}{\nu} = \frac{\text{Inertial forces}}{\text{Viscous forces}}$$

For water, $\mu = 0.01$ cm^2/s

D_h (μm)	v (cm/s)	Re ($D_h v/\mu$)
100	0.1	0.1
	100	100
200	0.1	0.2
	100	200
500	0.1	0.5
	100	500

Typical values of Reynolds number

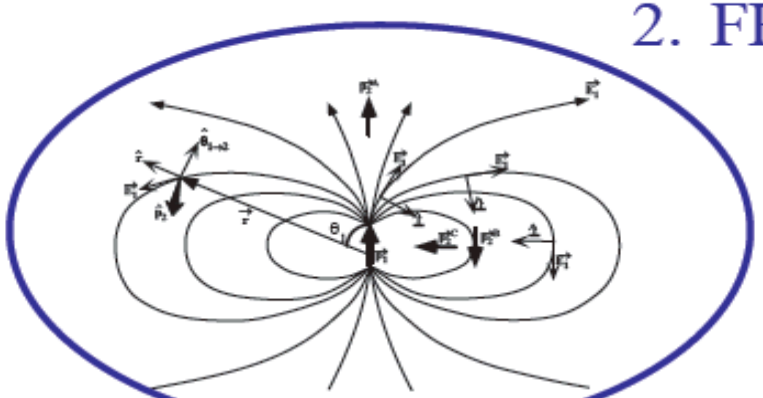
* Spermatozoa ~ 1×10^{-2}
* Blood flow in brain ~ 1×10^{2}
* Blood flow in aorta ~ 1×10^{3}

Onset of turbulent flow ~ 2.3×10^{3} for pipe flow to 10^{6} for boundary layers

* Typical pitch in Major League Baseball ~ 2×10^{5}
* Person swimming ~ 4×10^{6}
* Blue Whale ~ 3×10^{8}
* A large ship (RMS Queen Elizabeth 2) ~ 5×10^{9}

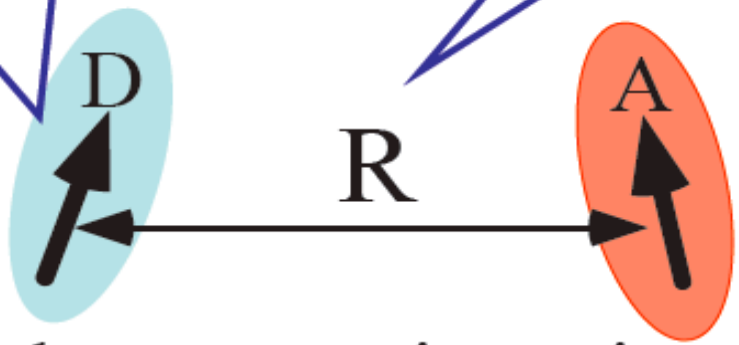
Dipole-dipole interaction

1. Van der Waal force
2. FRET



Rate of energy transfer

$$K_T = (1/\tau_D) \cdot [R_0/r]^6$$



R_0 is the Förster critical distance, τ_D is the donor lifetime in the absence of the acceptor, and r is the distance separating the donor and acceptor chromophores.

$$R_0 = 2.11 \times 10^{-2} \cdot [\kappa^2 \cdot J(\lambda) \cdot \eta^{-4} \cdot Q_D]^{1/6}$$

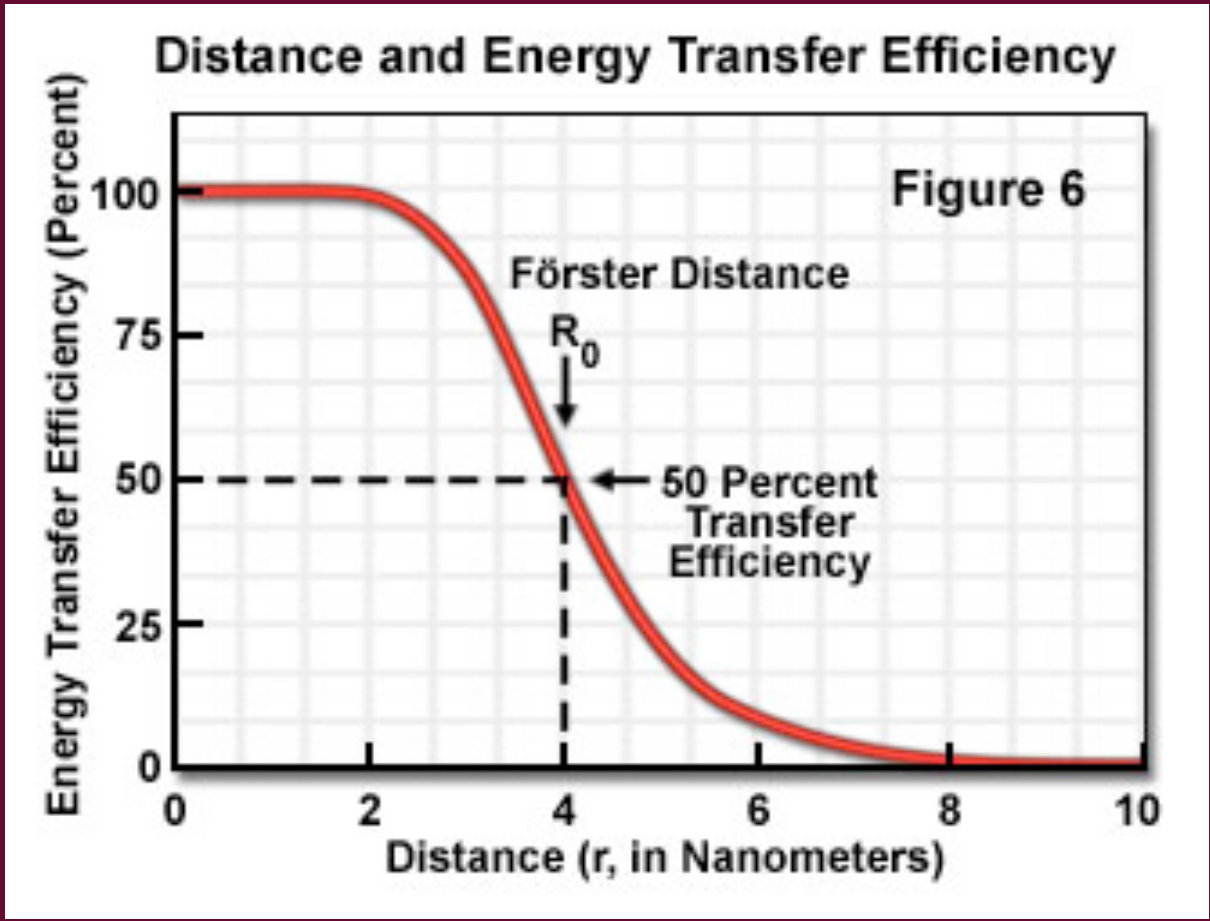
κ = kappa = orientation factor $\quad \kappa^2 \approx 2/3$

The efficiency of energy transfer, E(T), is a measure of the fraction of photons absorbed by the donor that are transferred to the acceptor, and is related to the donor-acceptor separation distance, r, by the equation:

$$r = R_0 \cdot [(1/E_T) - 1]^{1/6}$$

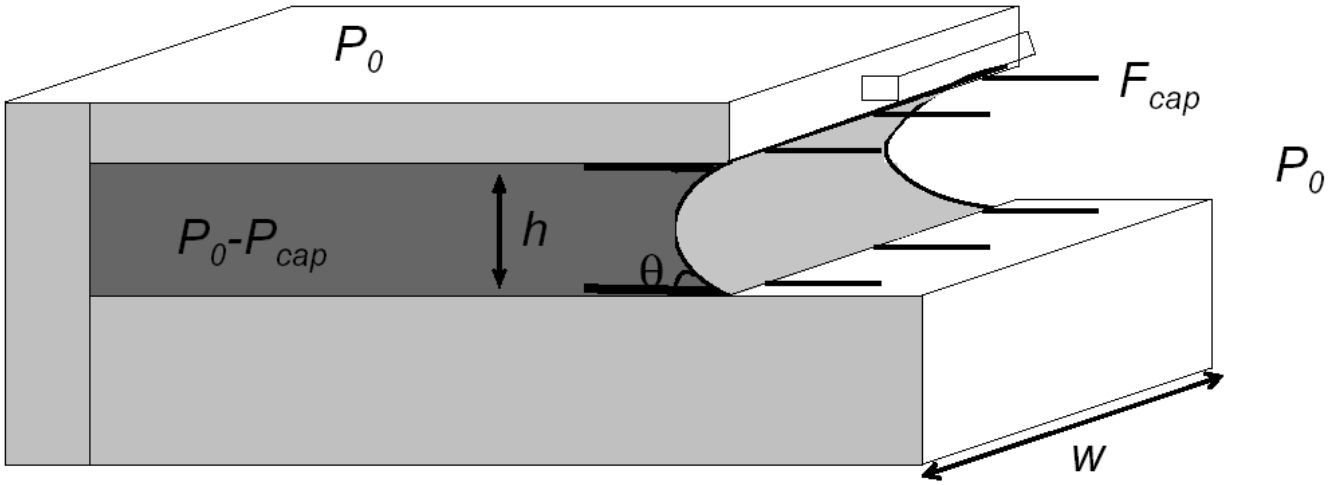
$$E_T = 1 - (\tau_{DA}/\tau_D)$$

where τ_{DA} is the donor lifetime in the presence of the acceptor and τ_D is the donor lifetime in the absence of the acceptor.



Capillary Forces

Capillary pressure



$$F_{cap} = 2w\gamma\cos\theta$$

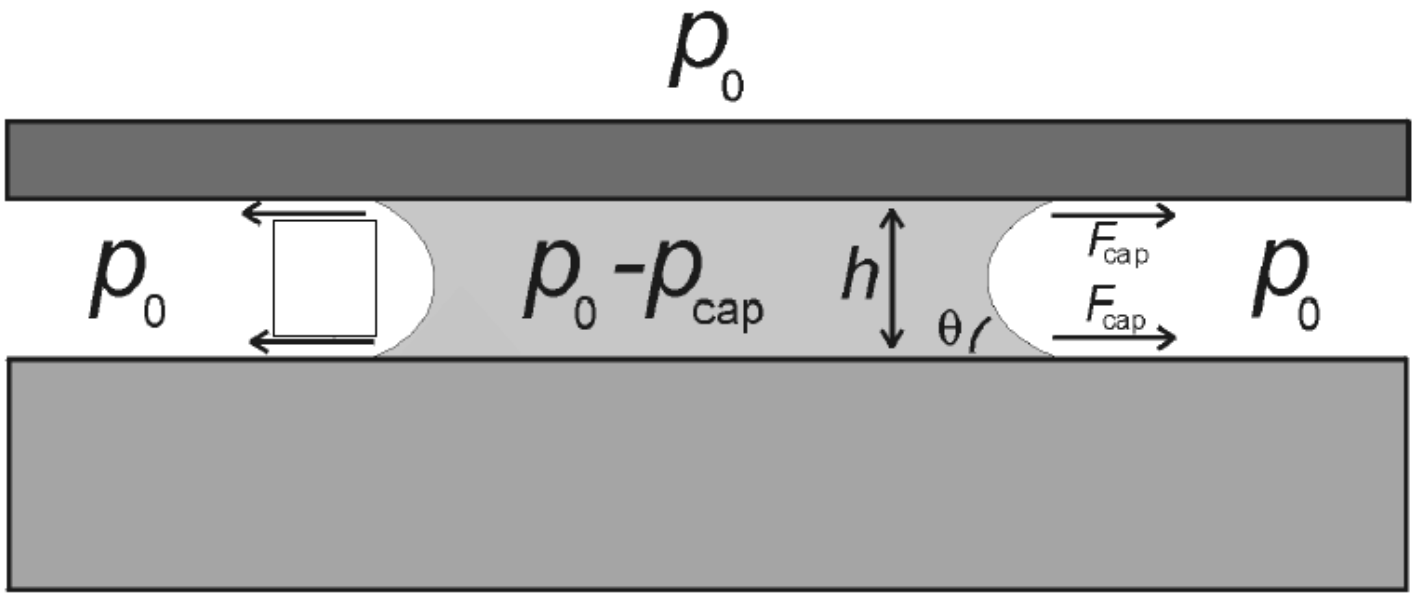
$$P_{cap} = \frac{2\gamma\cos\theta}{h}$$

γ : surface tension (Nm^{-1})

θ : contact angle

Pressure increases with *1/h* !!

Capillarity induced negative pressure

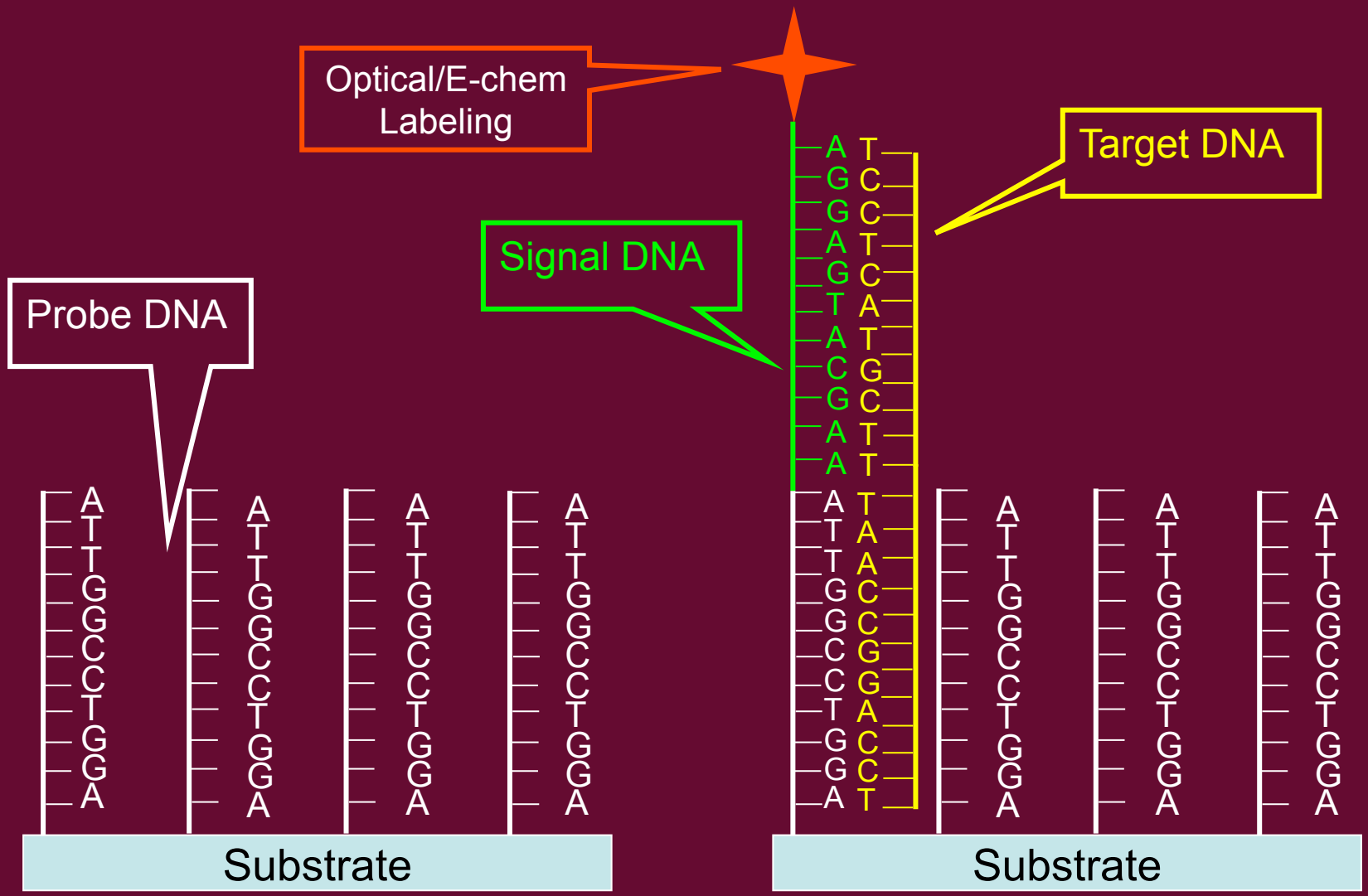


$$p_{cap} = \frac{2\gamma \cos\theta}{h}$$

h = 108 nm, γ = 0.07 Nm^{-1} θ = 18°

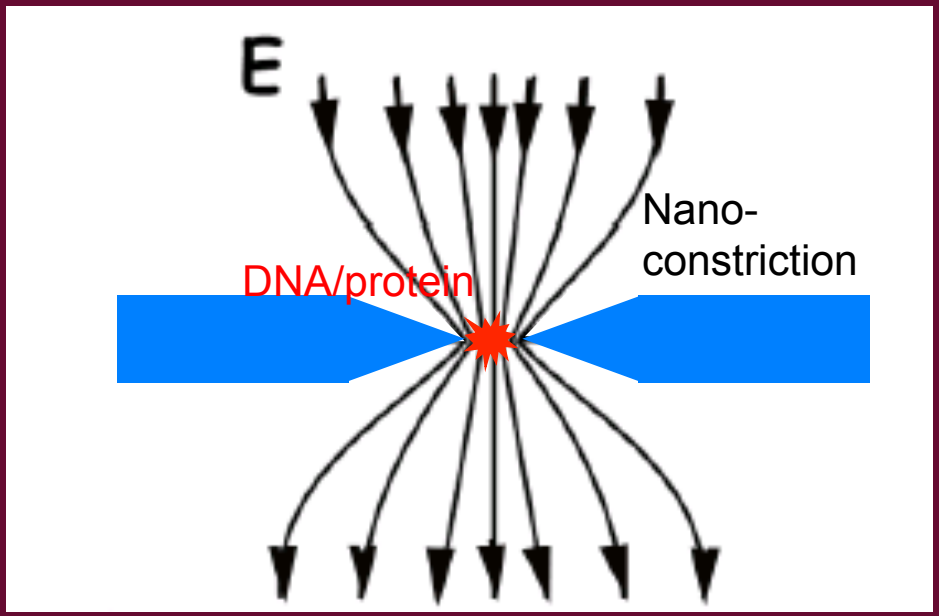
$\rightarrow p_0 - p_{cap}$ = -12 bar

Principles of DNA Hybridization & Detection



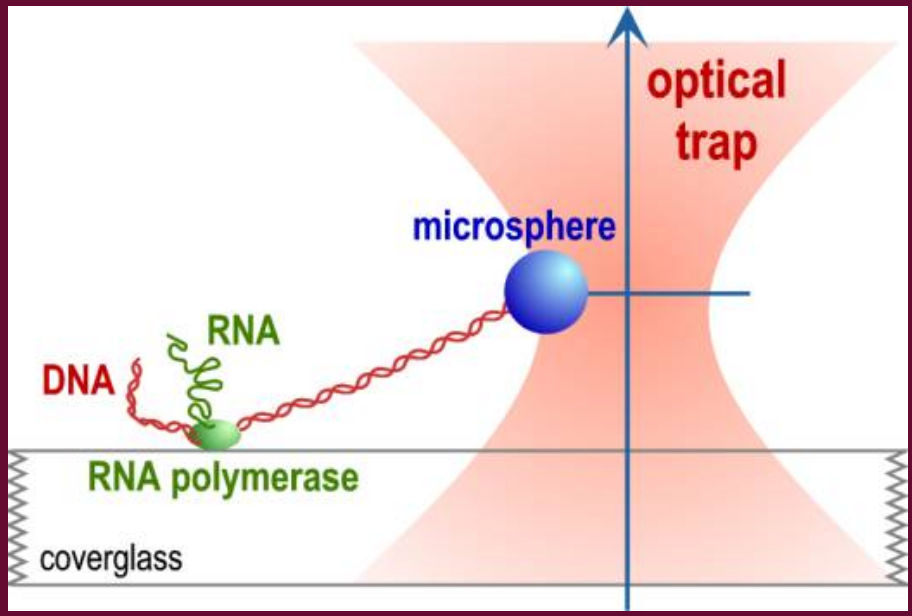
EDEP Molecular Trap vs. Optical Trap

EDEP molecular trap



Electric field focused
at the constriction

Optical trap



Electric field focused
at the focal point