Self-assembly and Nanotechnology 10.524

Lecture 5. Biomolecular Self-assembly (and Detection)

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& UML CHN/NCOE Nanomanufacturing Center)

Lecture 6: Biomolecular Self-assembly

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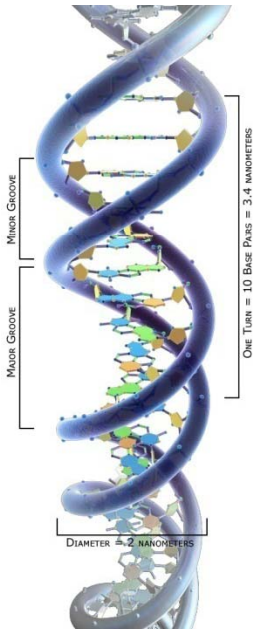
Biomolecular Self-assembly

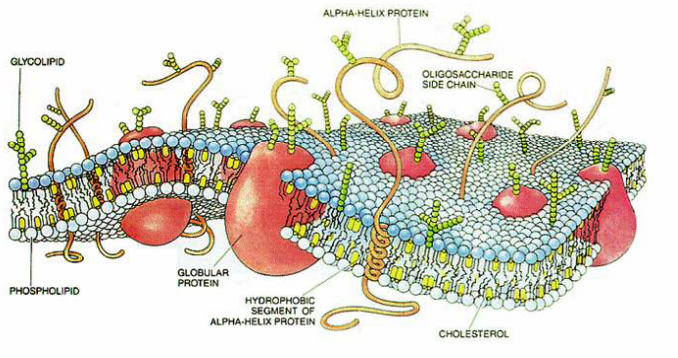
Definitions

A **biomolecule** is a chemical compound that naturally occurs in living organisms. Biomolecules consist primarily of carbon and hydrogen, along with nitrogen, oxygen, phosphorus and sulfur. Other elements sometimes are incorporated but are much less common.



DNA

Proteins



Cell Membrane

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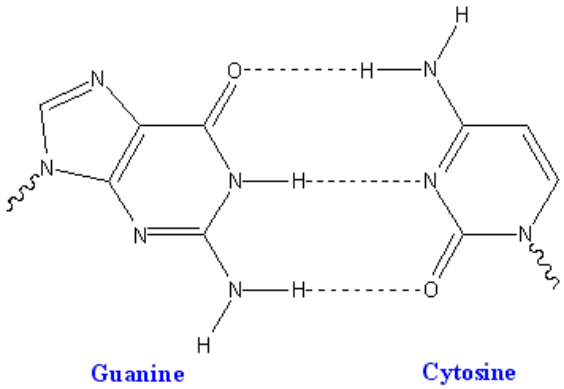
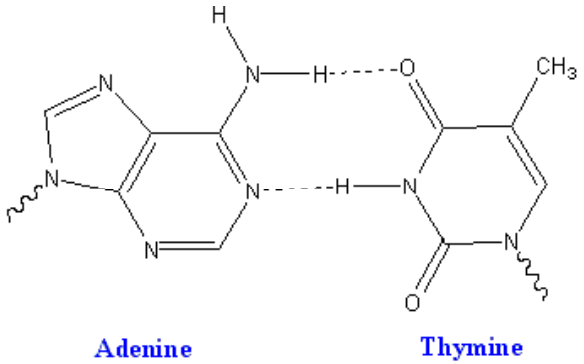
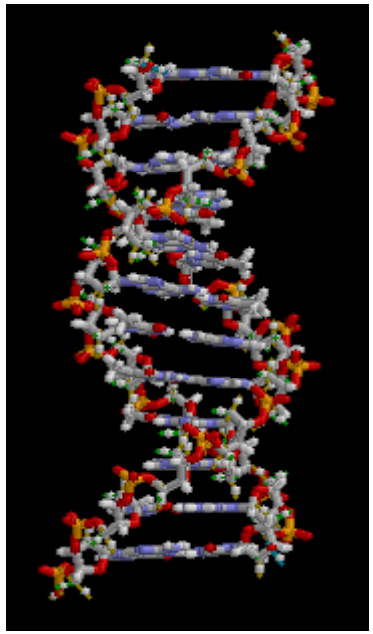
DNA Self-Assembly

Deoxyribonucleic acid (DNA) is a nucleic acid that contains the genetic instructions for the development and function of living organisms.

The DNA double helix is held together by hydrogen bonds between the bases attached to the two strands. The four bases found in DNA are adenine (abbreviated A), cytosine (C), guanine (G) and thymine (T).





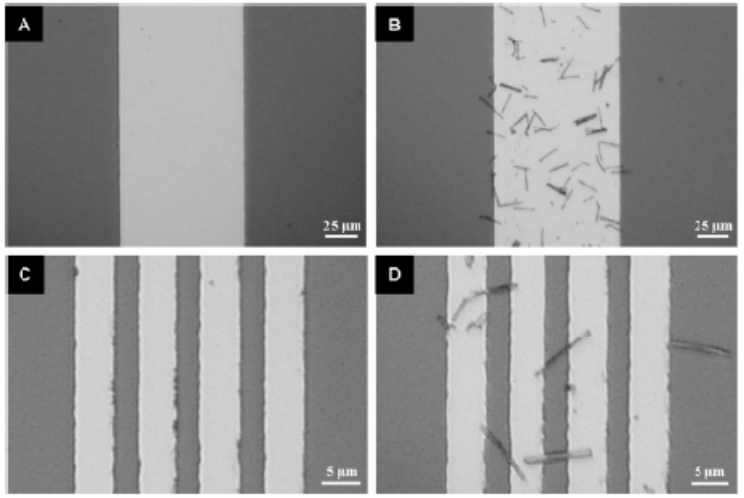


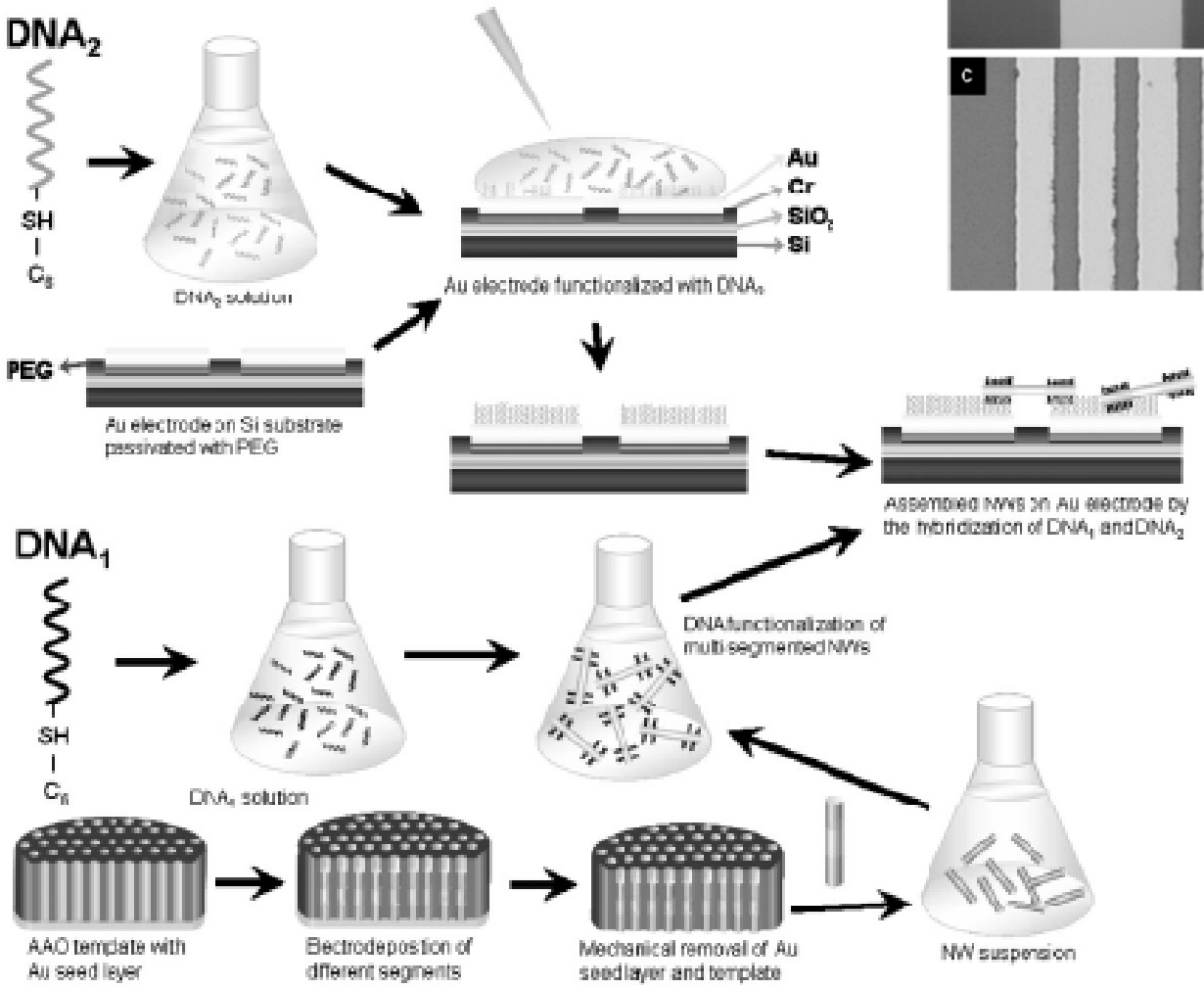
DNA self-assembly is the most advanced and versatile system known for programmable construction of patterned systems on the molecular scale

DNA Assisted Self-Assembly of Nanowires

DNA_1: 5′-SH-C_6-TTTTTTTTTTTTTTTTTTT AAT ATT GAT AAG GAT

DNA_2: 5′-SH-C_6-TTTTTTTTTTTTTTTTTTT ATC CTT ATC AAT ATT

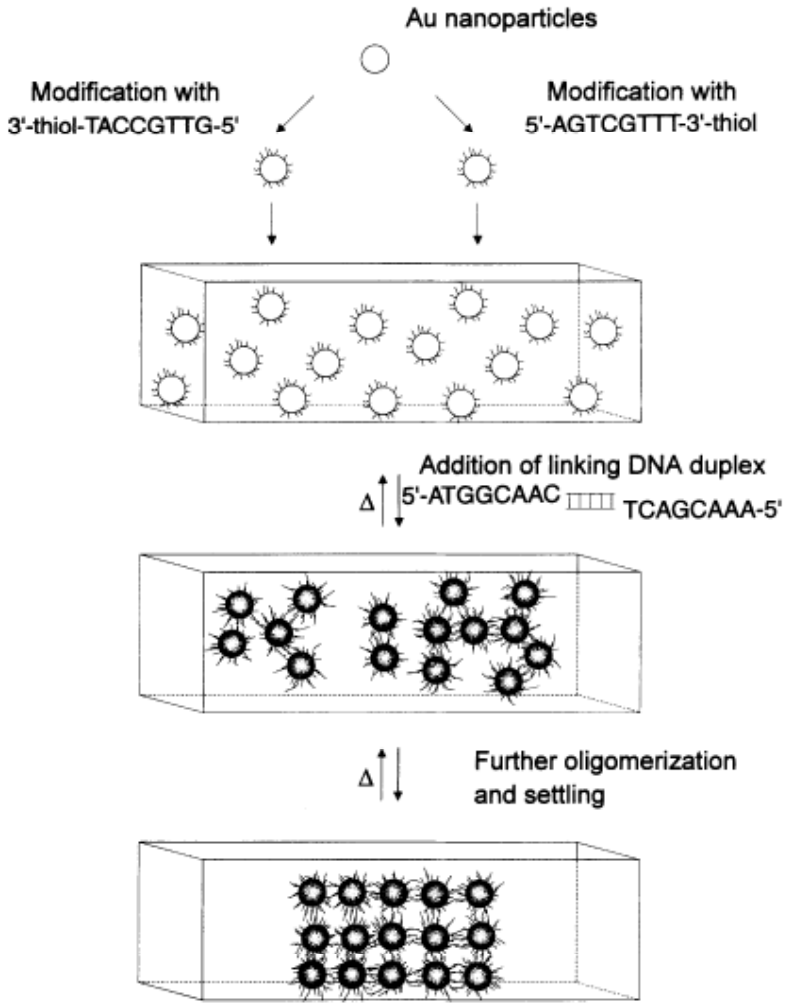


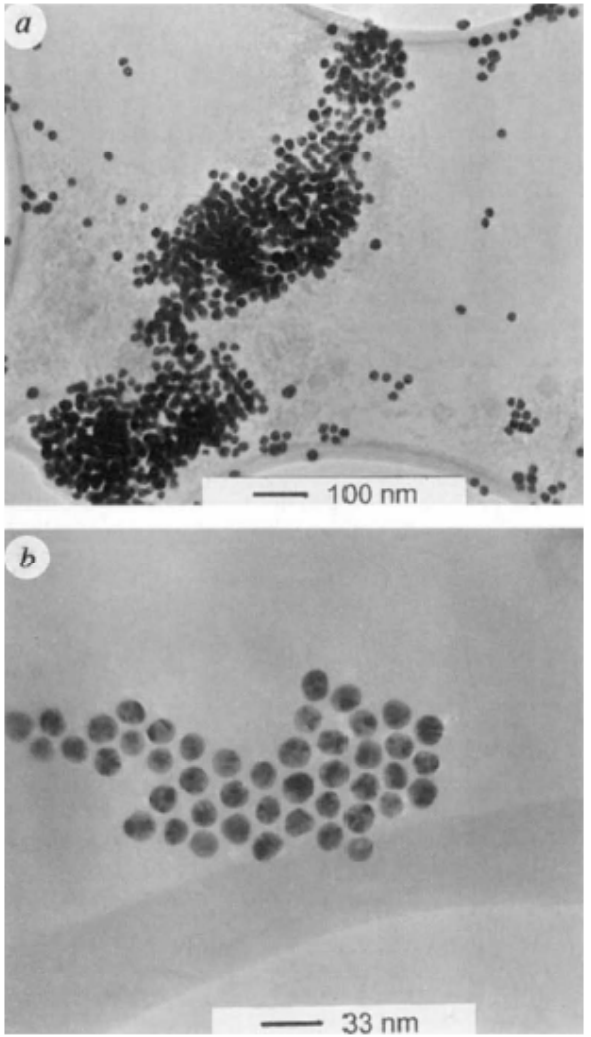


Electroanalysis 19, 2007, No. 22, 2287 – 2293

Nanostructure Fabrication by Bimolecular Self-assembly

DNA Based Nanoparticles Assembly





Self-assembly and Nanotechnology

Nature, *382*, 607-609 (1996)

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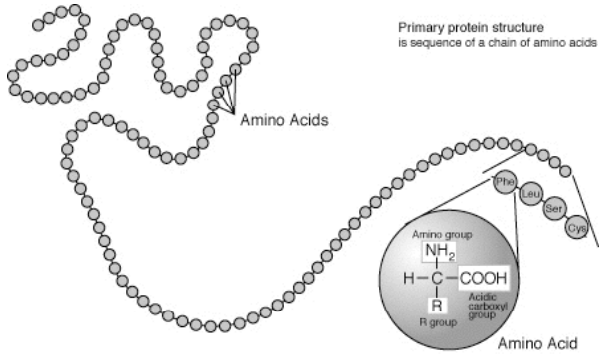
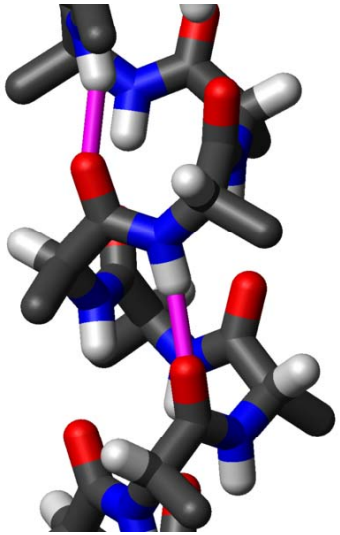
Protein Self-Assembly (Folding)

Protein structures

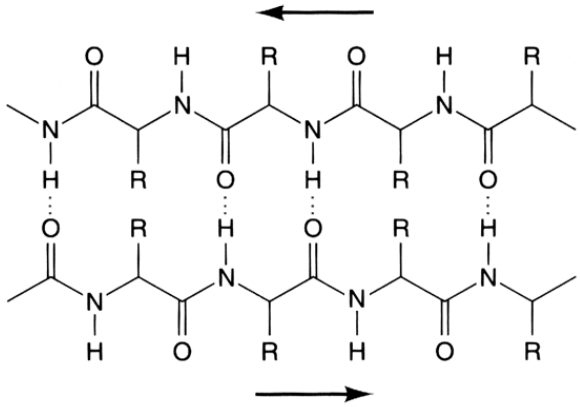
Primary structure: amino acid sequence



Secondary structure: regularly repeating local structures stabilized by hydrogen bonds



alpha helix (α-helix)



β sheet (also β-pleated sheet)

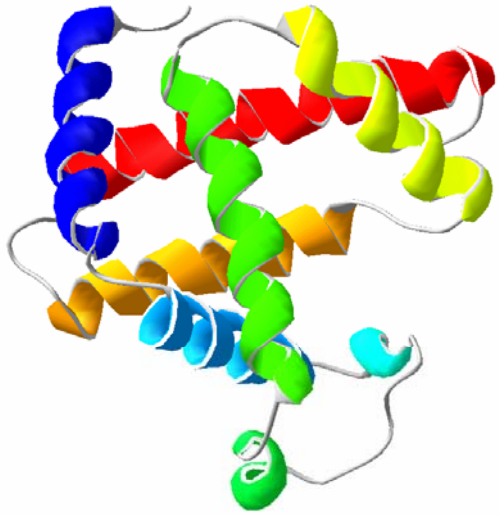
From Wikipedia

Protein Self-Assembly (Folding)

Protein structures

Tertiary structure: the overall shape of a single protein molecule; the spatial relationship of the secondary structures to one another.

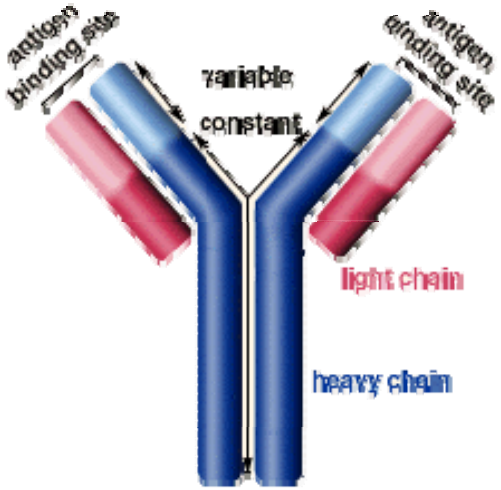
Tertiary structure is generally stabilized by nonlocal interactions, most commonly the formation of a hydrophobic core, but also through salt bridges, hydrogen bonds, disulfide bonds, and even post-translational modifications.



Quaternary structure: the shape or structure that results from the interaction of more than one protein molecule, usually called *protein subunits* in this context, which function as part of the larger assembly or protein complex.

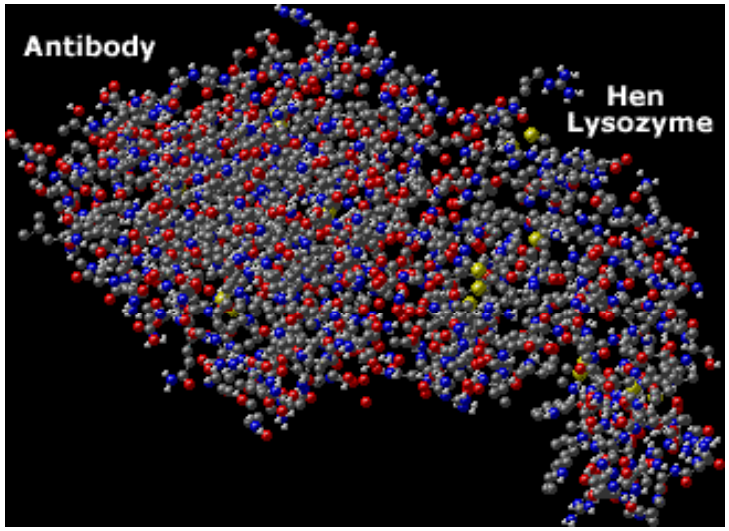
From Wikipedia

Antibody-Antigen Interactions



Antibody Structure

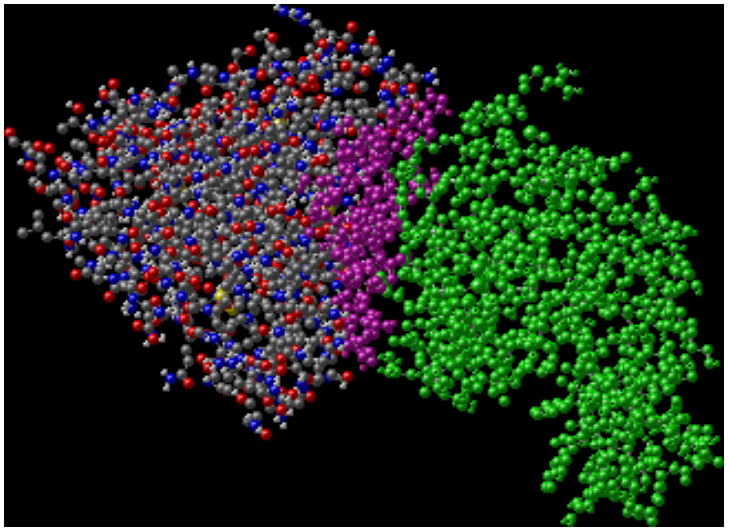
Antibodies are immune system-related proteins called immunoglobulins. Each antibody consists of four polypeptides–two heavy chains and two light chains joined to form a "Y" shaped molecule. The amino acid sequence in the tips of the "Y" varies greatly among different antibodies. This variable region, composed of 110-130 amino acids, give the antibody its specificity for binding antigen.



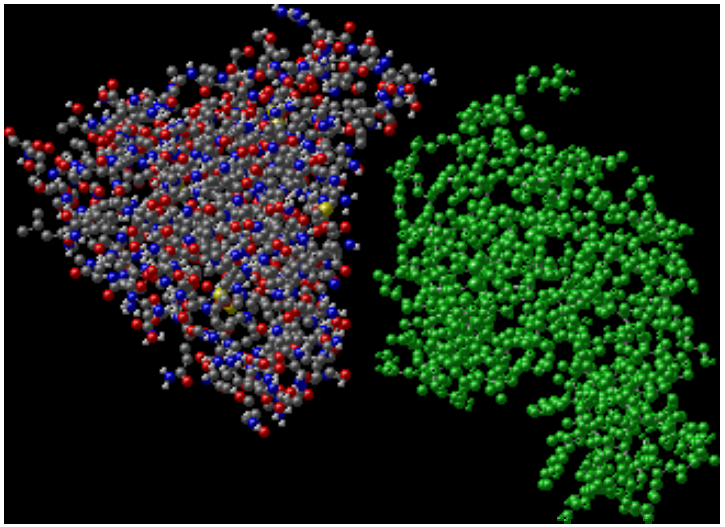
This image represents the structure of an antibody's variable region (Fab) complexed with an antigen, in this case hen egg white lysozyme.

http://www.biology.arizona.edu/IMMUNOLOGY/tutorials/antibody/structure.html

Antibody-Antigen Interactions



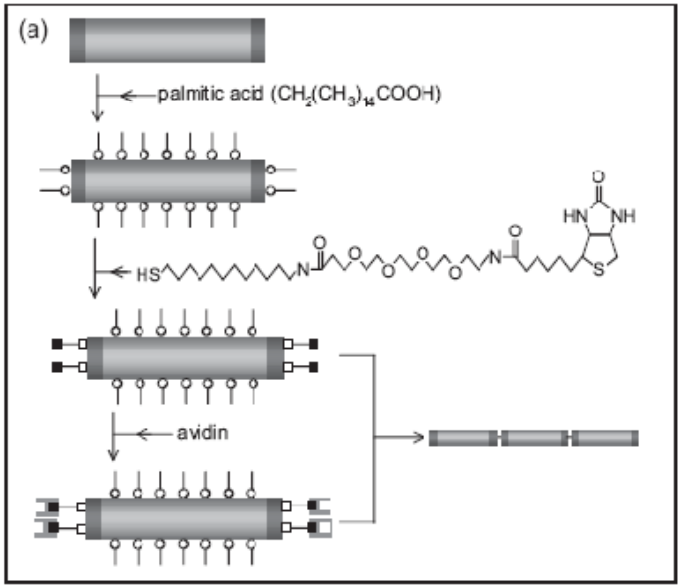
The hypervariable (HV) regions of a Fab, representing both light and heavy chains, are highlighted in purple. The antigen is green. The part of the antigen in direct contact with the antibody is called the antigenic determinant, or epitope

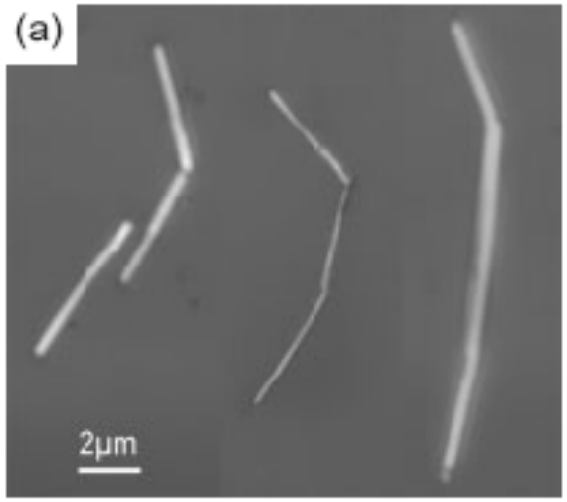


In this view, the HV regions of the Fab have been deleted. The framework (FR) regions of the antibody do not contact the antigen.

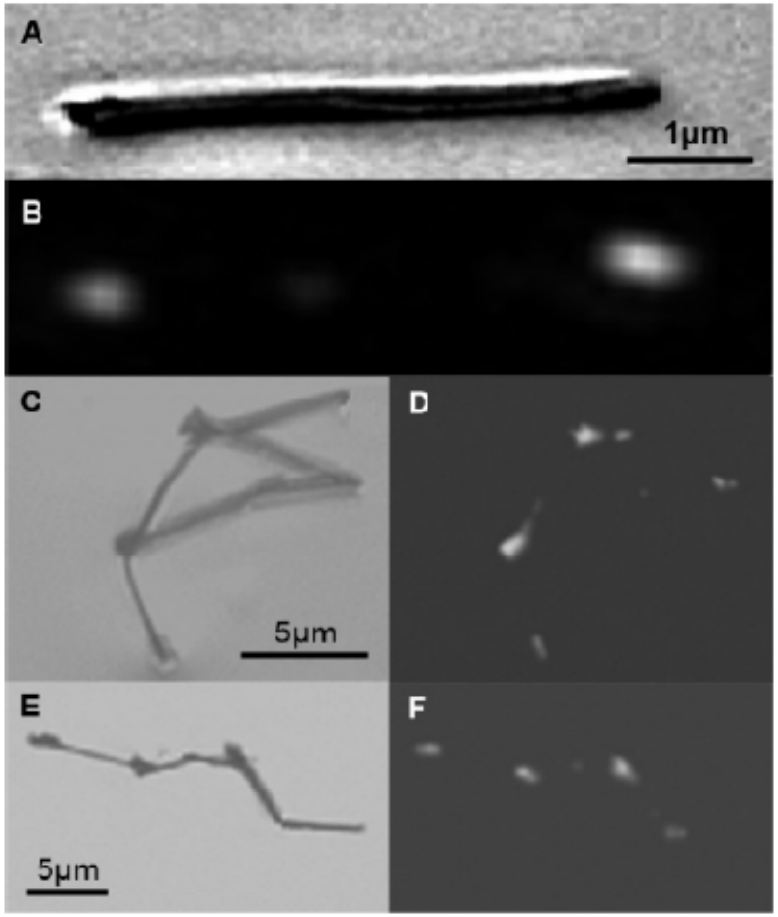
http://www.biology.arizona.edu/IMMUNOLOGY/tutorials/antibody/structure.html

Nanostructure Fabrication by Bimolecular Self-assembly





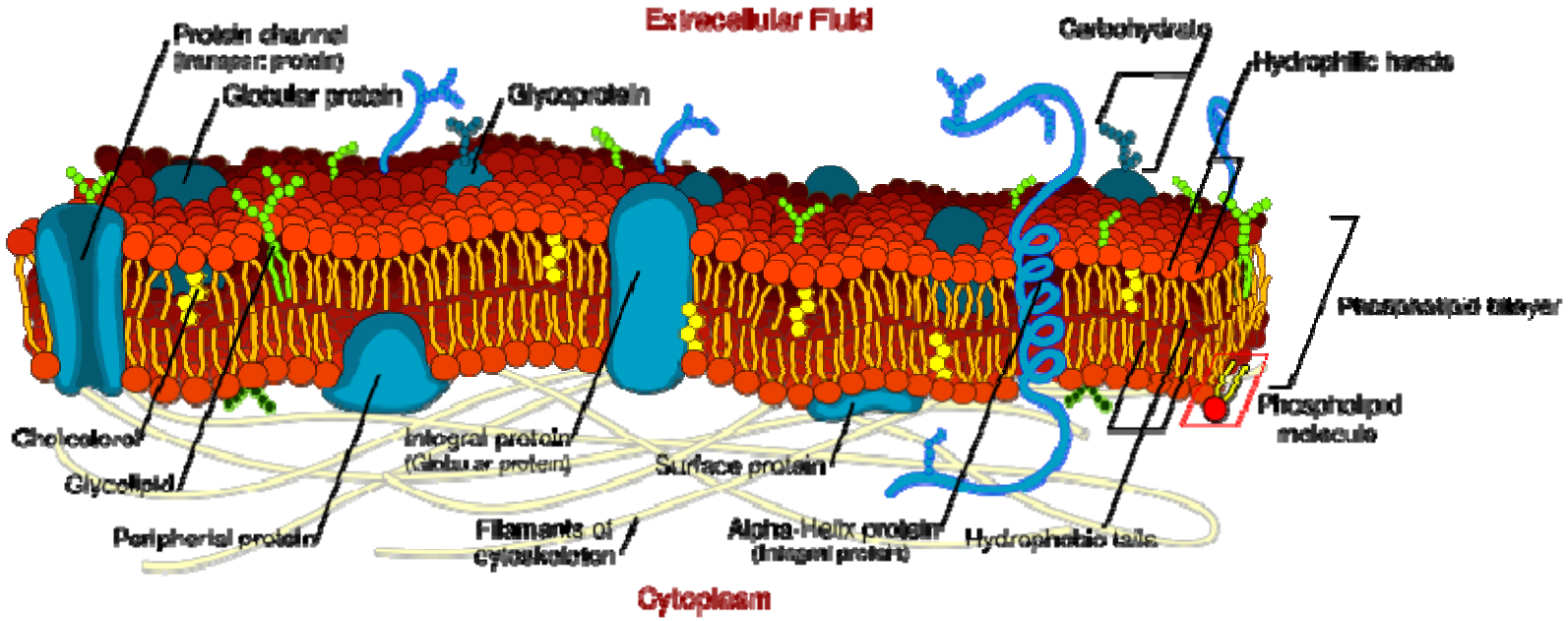
[Biotin-Avidin Linker for Nanowire Assembly]



Nano Lett., **2004,** *4*, 1163-1165

Cell Membranes (Lipid Bilayer)

Illustration of a cell membrane



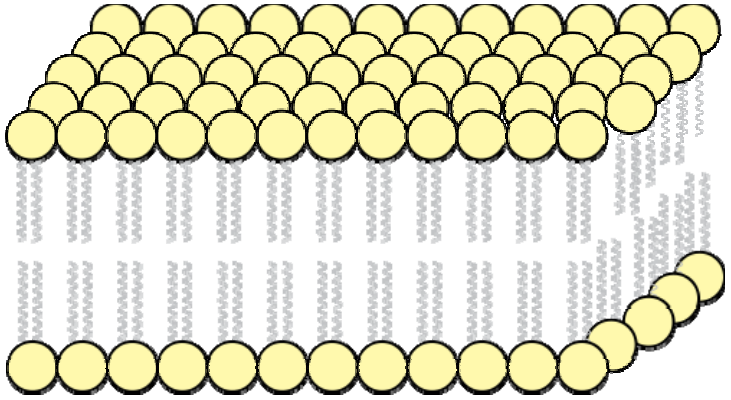
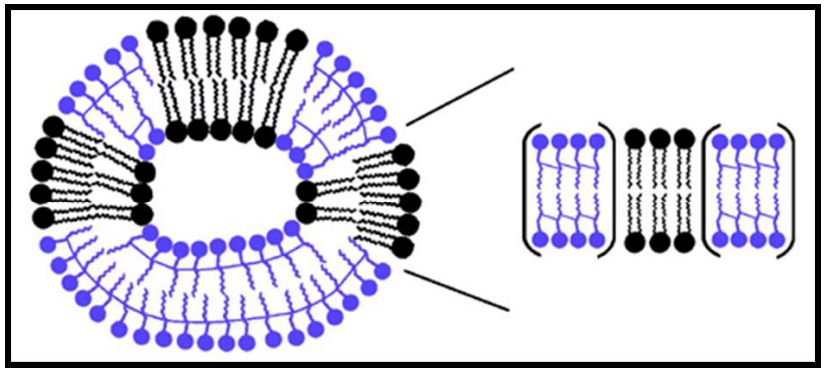


Diagram of the arrangement of amphipathic lipid molecules to form a lipid bilayer. The polar yellow head groups separate the grey hydrophobic tails from the aqueous cytosolic and extracellular environments

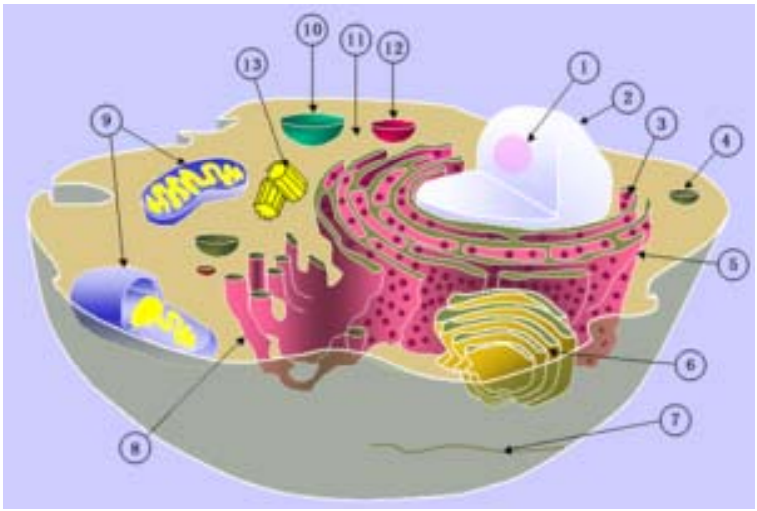
Vesicles

Vesicle is a relatively small and enclosed compartment, separated from the cytosol by at least one lipid bilayer. If there is only one lipid bilayer, they are called *unilamellar* vesicles; otherwise they are called *multilamellar*. Vesicles store, transport, or digest cellular products and waste.



Example: Bio-mimetic lipid/PDA vesicles

A schematic description of a chromatic vesicle composed of phospholipids (black) and polydiacetylene (PDA) (blue). These particles form bio-mimetic bilayers constituting a useful platform for studying membrane processes, such as peptide-membrane interactions, pore formation, drug permeation through lipid barriers, and others.



Biological Cell

Schematic showing the cytoplasm, with its components (or *organelles*), of a typical animal cell. Organelles: (1) nucleolus (2) nucleus (3) ribosome (4) vesicle (5) rough endoplasmic reticulum (6) Golgi apparatus (7) cytoskeleton (8) smooth endoplasmic reticulum (9) mitochondria (10) vacuole (11) cytosol (12) lysosome (13) centriole.

Vesicles Made by Block Copolymers

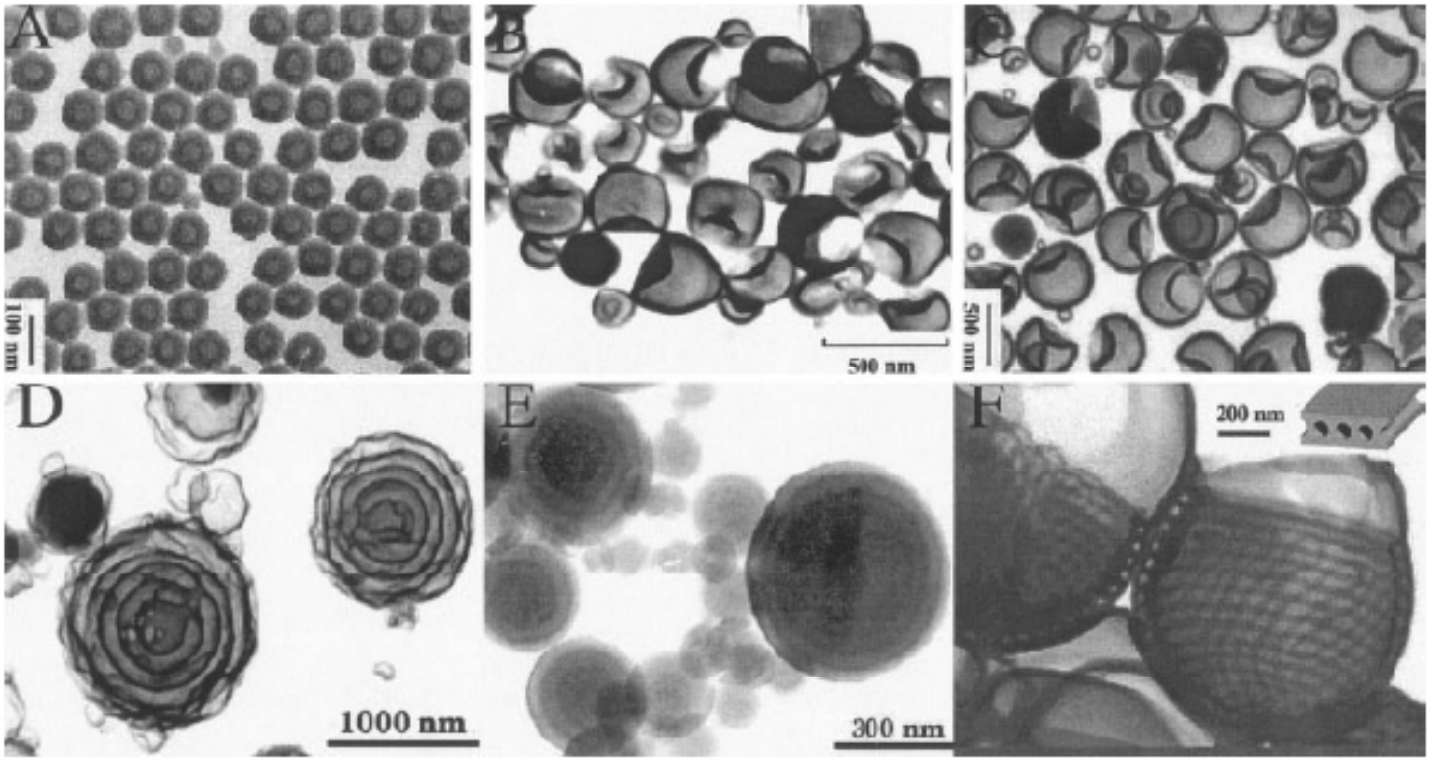


Figure 1. Representative micrographs of various types of vesicles: (A) small uniform vesicles (PS_{410}-*b*-PAA_{13}), (B) large polydisperse vesicles (PS_{100}-*b*-PEO_{30}), (C) entrapped vesicles (PS_{200}-*b*-PAA_{20}), (D) hollow concentric vesicles (PS_{132}-*b*-PAA_{20}), (E) onions (PS_{250}-*b*-$P4VPDecI_{70}$), and (F) vesicles with tubes in the wall (PS_{130}-*b*-PEO_{30}). (From S. Burke et al., Macromol Symp 2001, 175, 273.)

Journal of Polymer Science: Part B: Polymer Physics, Vol. 42, 923–938 (2004)

Vesicles Made by Block Copolymers

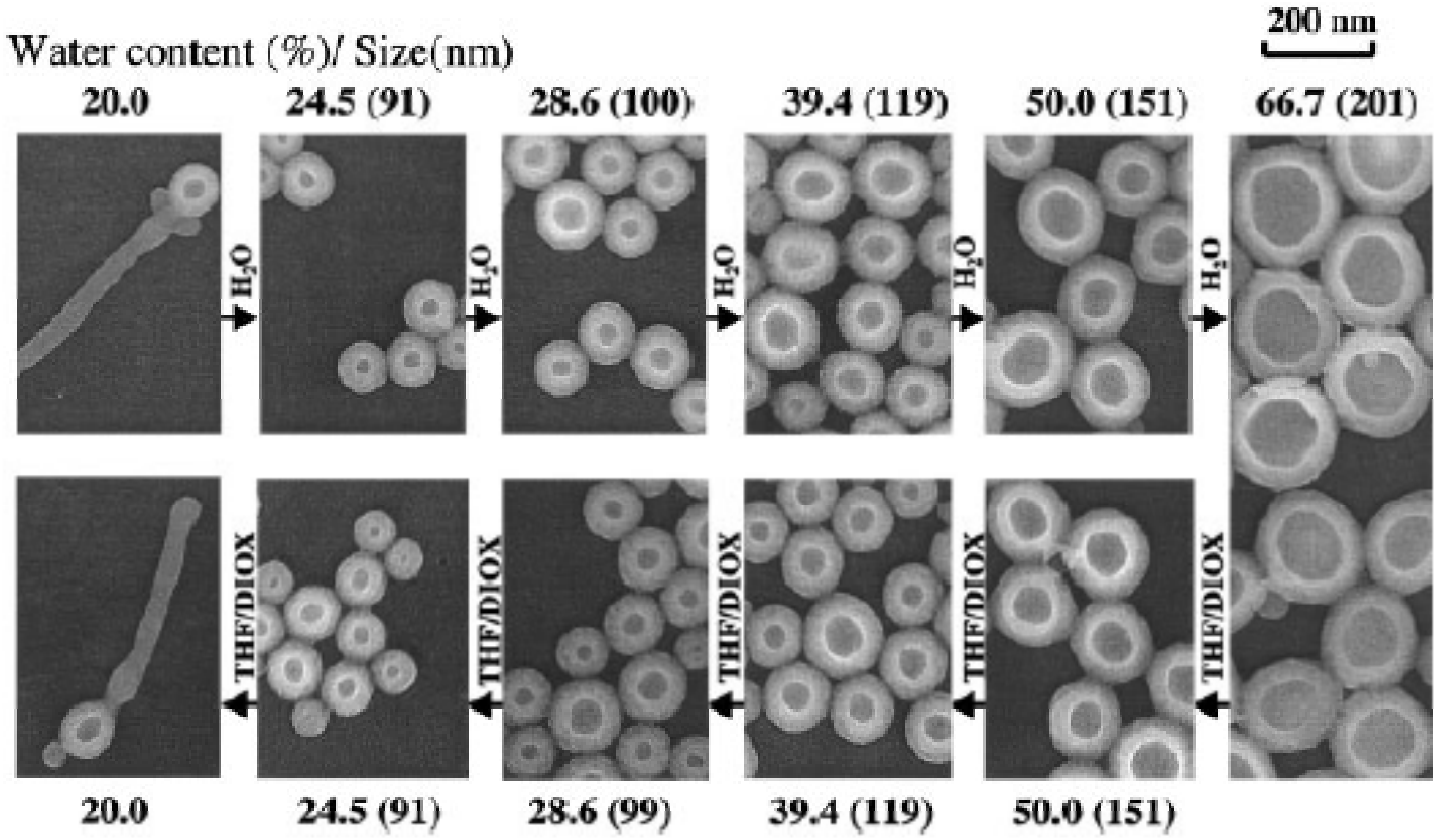


Figure 3. Reversibility of vesicle sizes in response to increasing or decreasing water contents for PS_{300}-*b*-PAA_{44} vesicles in a THF/dioxane (44.4/55.6) solvent mixture. (From L. Luo and A. Eisenberg, Langmuir 2002, 18, 1952.)

Journal of Polymer Science: Part B: Polymer Physics, Vol. 42, 923–938 (2004)

Vesicles Made by Block Copolymers

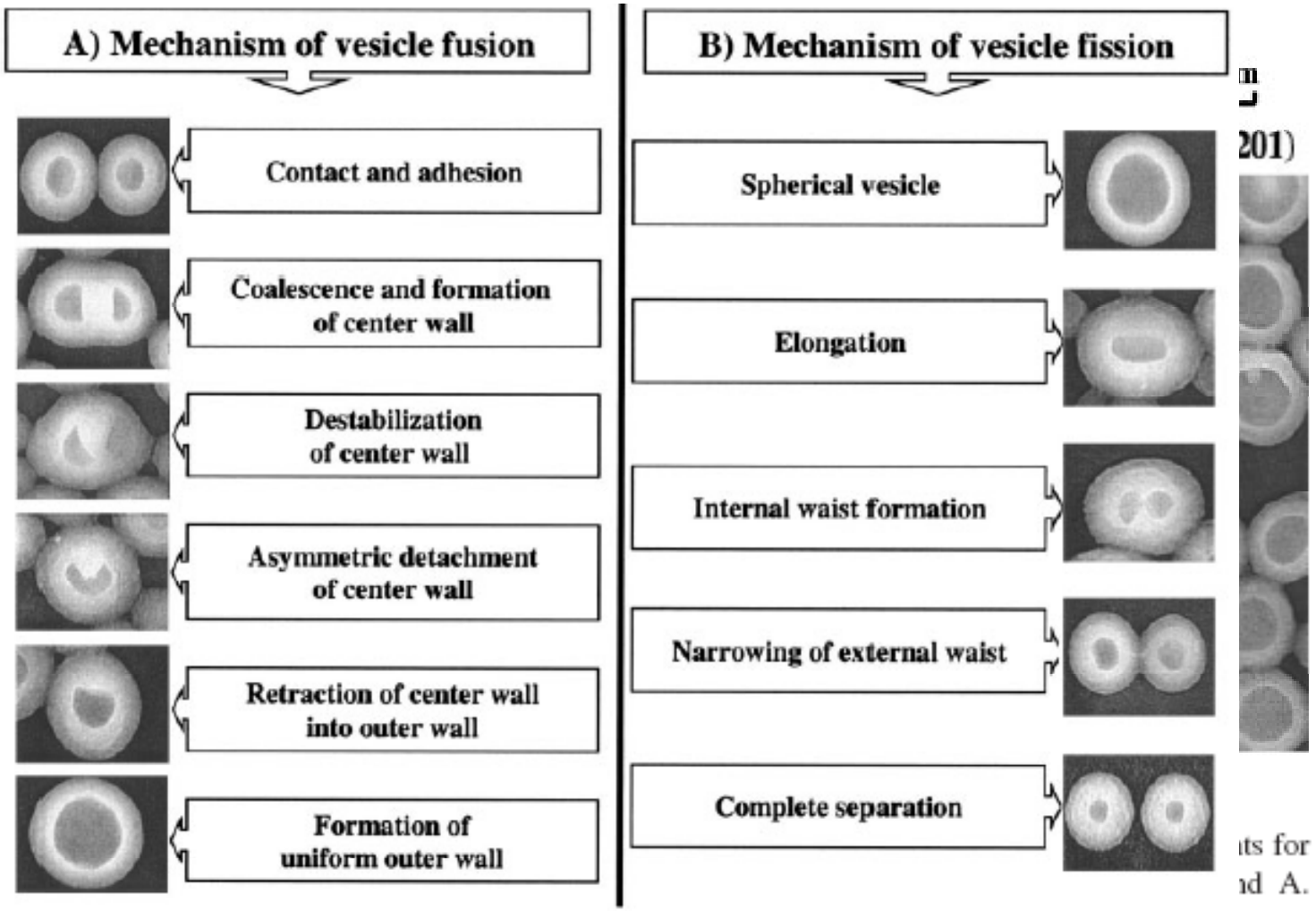
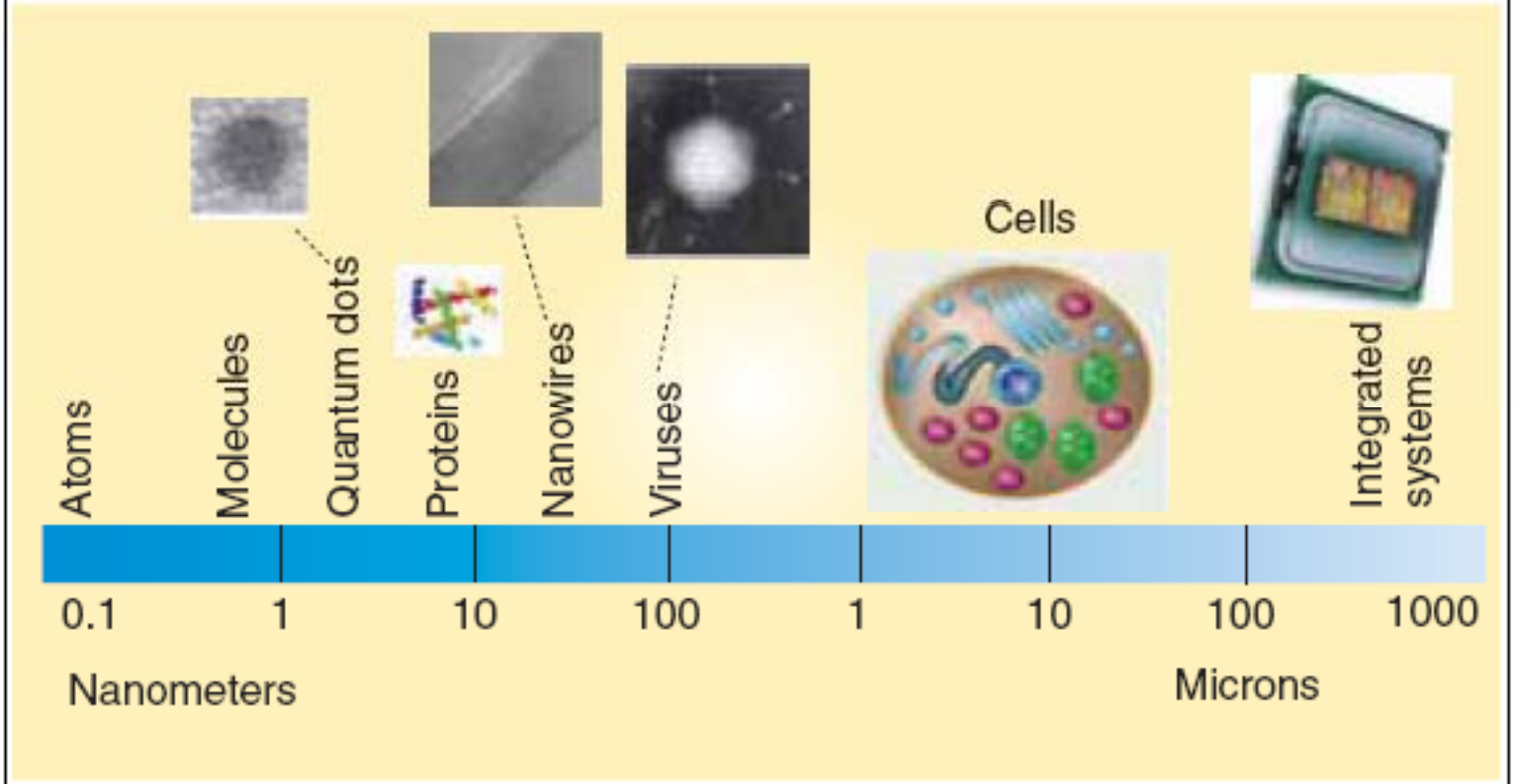


Figure 4. Possible mechanisms of (A) the fusion of vesicles and (B) the fission of a vesicle. (From L. Luo and A. Eisenberg, Langmuir 2001, 17, 6804.)

Journal of Polymer Science: Part B: Polymer Physics, Vol. 42, 923–938 (2004)

Case Study: Nanowire-Based Biosensors

Figure 1. Comparison of the sizes of biological, chemical and nanoscale structures, assemblies and systems.



Materials Today, 2005, 20

Nanomedicine, *1(1),* 51-65 (2006)

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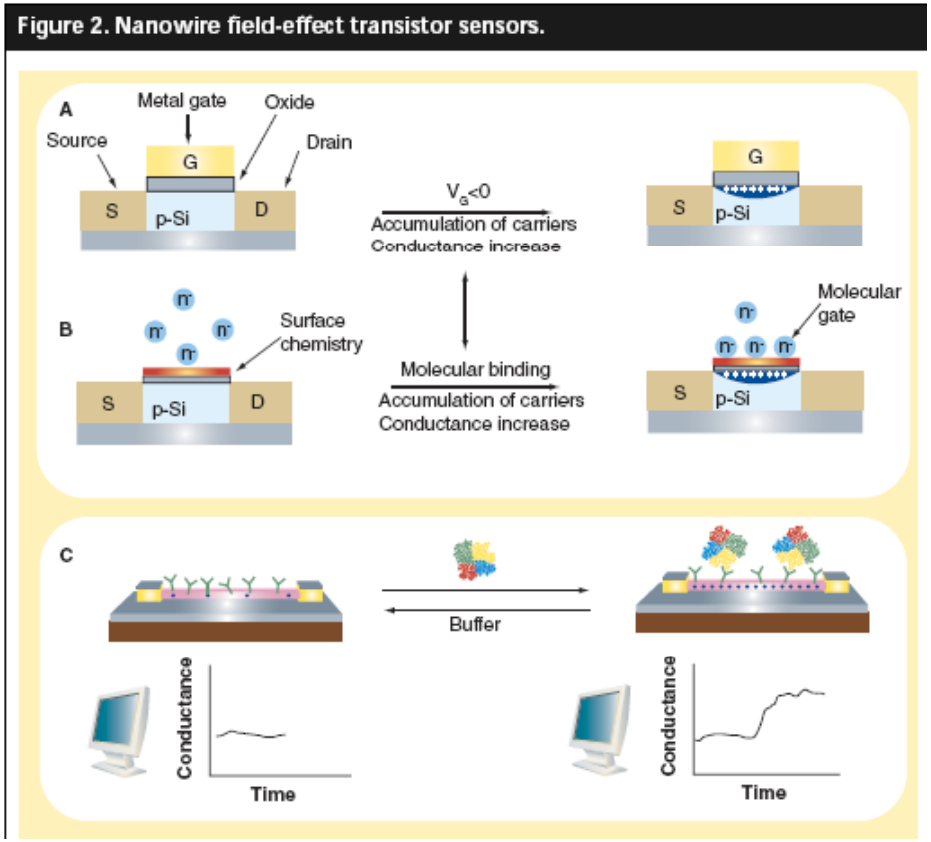
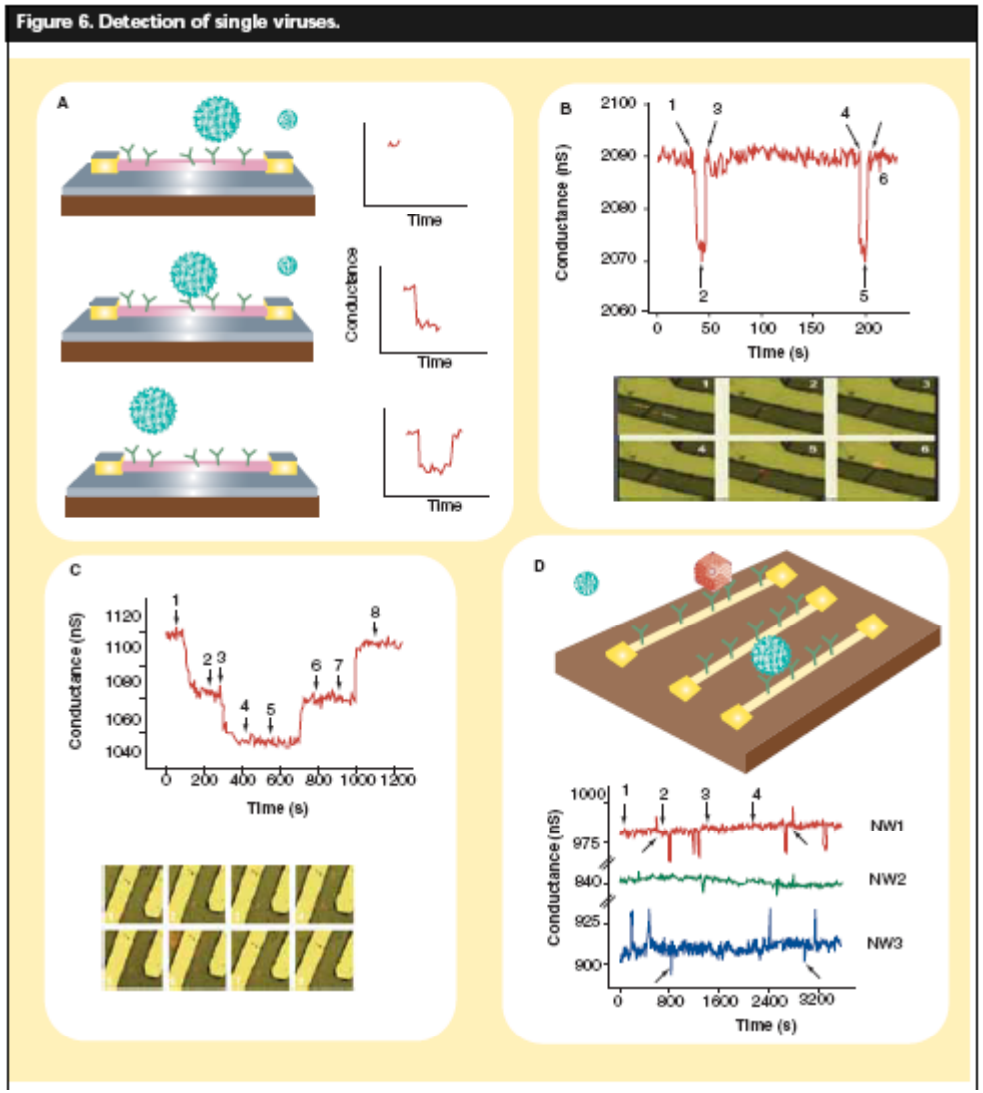
Case Study: Nanowire-Based Biosensors



(A) Schematic of a field-effect transistor (FET); (B) schematic of electrically-based sensing using FET devices. The binding of a "charged or polar" biological or chemical species to the chemically modified gate dielectric is analogous to applying a voltage using a gate electrode as shown in A. (C) A nanowire device configured as a sensor with antibody receptors (green) and binding of a protein with net negative charge yields an increase in the conductance. (D) A prototype nanowire sensor biochip with integrated microfluidic sample delivery

Nanomedicine, *1(1),* 51-65 (2006)

Case Study: Nanowire-Based Biosensors



(A) Schematic of a single virus binding and unbinding to the surface of a silicon nanowire device modified with antibody receptors; (B) simultaneous conductance and optical data for a silicon nanowire device with a low-density of antibody receptor units (C) high-density of anti-body (D) schematic of multiplexsed single virus detection.

Nanomedicine, *1(1),* 51-65 (2006)