Nanotechnology in the life sciences

A FRONTIS LECTURE SERIES

organized by

Pieter Stroeve

Department of Chemical Engineering and Materials Science

University of California, Davis

Davis, CA 95616, USA

WAGENINGEN UR
For quality of life

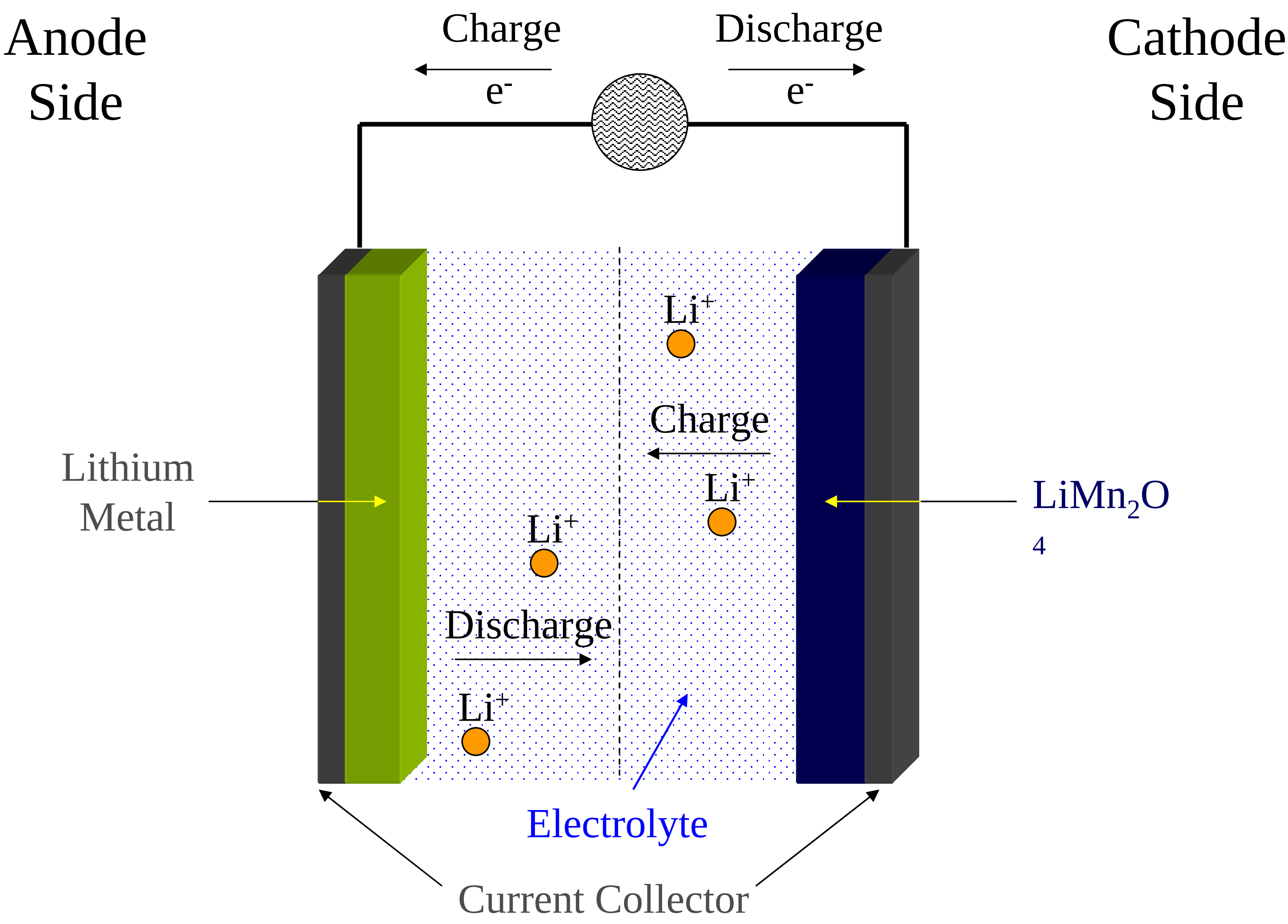
Nanotechnology in the life sciences

February 13	13:30	Pieter Stroeve (UC Davis)- Size, measurement and sensing
	14:30	Mieke Kleijn (WUR)- Surface forces using AFM
February 20	**13:30**	**Pieter Stroeve- (Bio)materials**
	14:30	**Ernst Sudholter (WUR)- Hybrid organic semiconductor FETs**
February 27	13:30	Pieter Stroeve- Self assembling molecular structures
	14:30	Richard Schasfoort (U Twente)- Surface modification and microfabrication strategies
Friday, March 5	13:30	Pieter Stroeve- Environment
	14:30	Keurentje (TU Eindhoven)- Micellar systems for nanoscale engineering of reaction and separation processes
Friday, March 12	13:30	Pieter Stroeve- Life sciences and medicine
	14:30	Ton Visser (WUR)- Single-molecule fluorescence in microfluidic devices

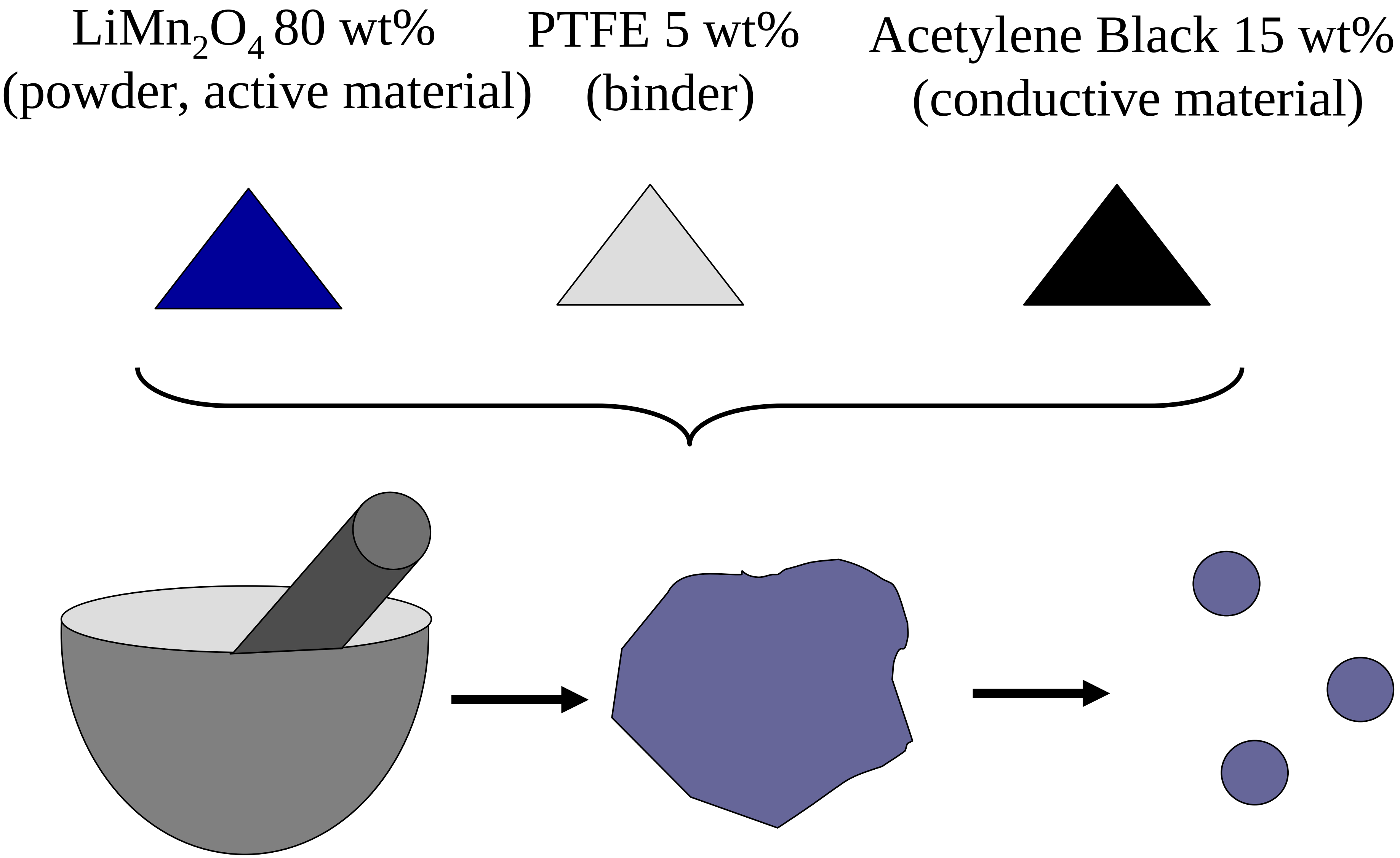
Nanotechnology: (bio)materials

- Rocket science?
- Engineered proteins for nanotechnology
- GeneChip
- Nanotubes, nanowires, nanocables
- Protein separation in nanopores

Lithium ion battery



Creation of $LiMn_2O_4$ Cathode



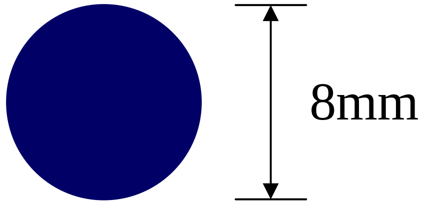
$LiMn_2O_4$ 80 wt%
(powder, active material)

PTFE 5 wt%
(binder)

Acetylene Black 15 wt%
(conductive material)

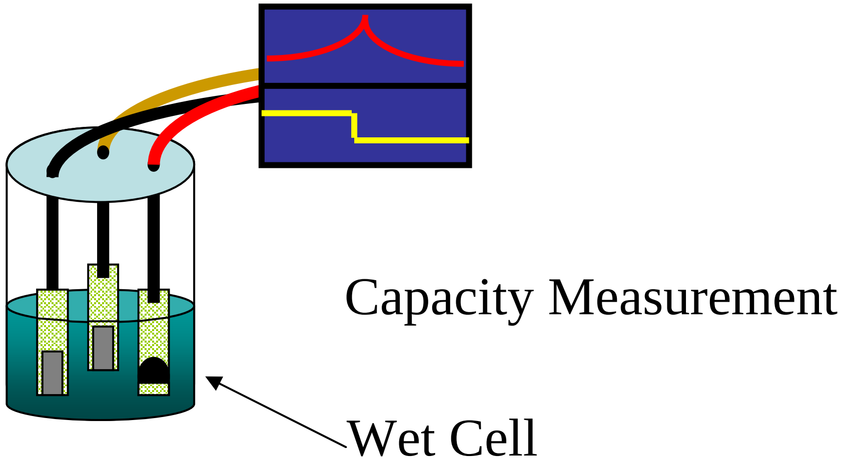
Experimental stages

1



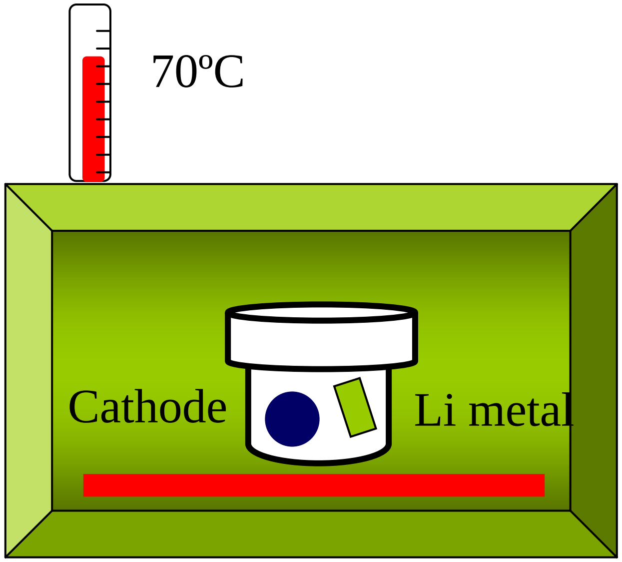
As Prepared

2



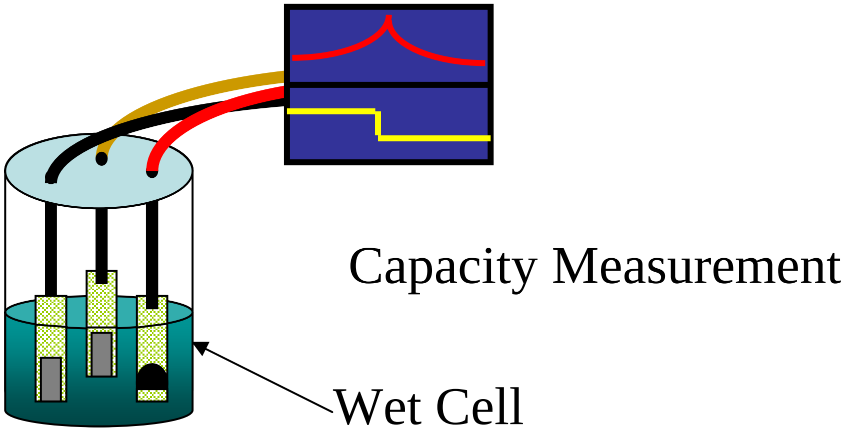
Before Storage

3



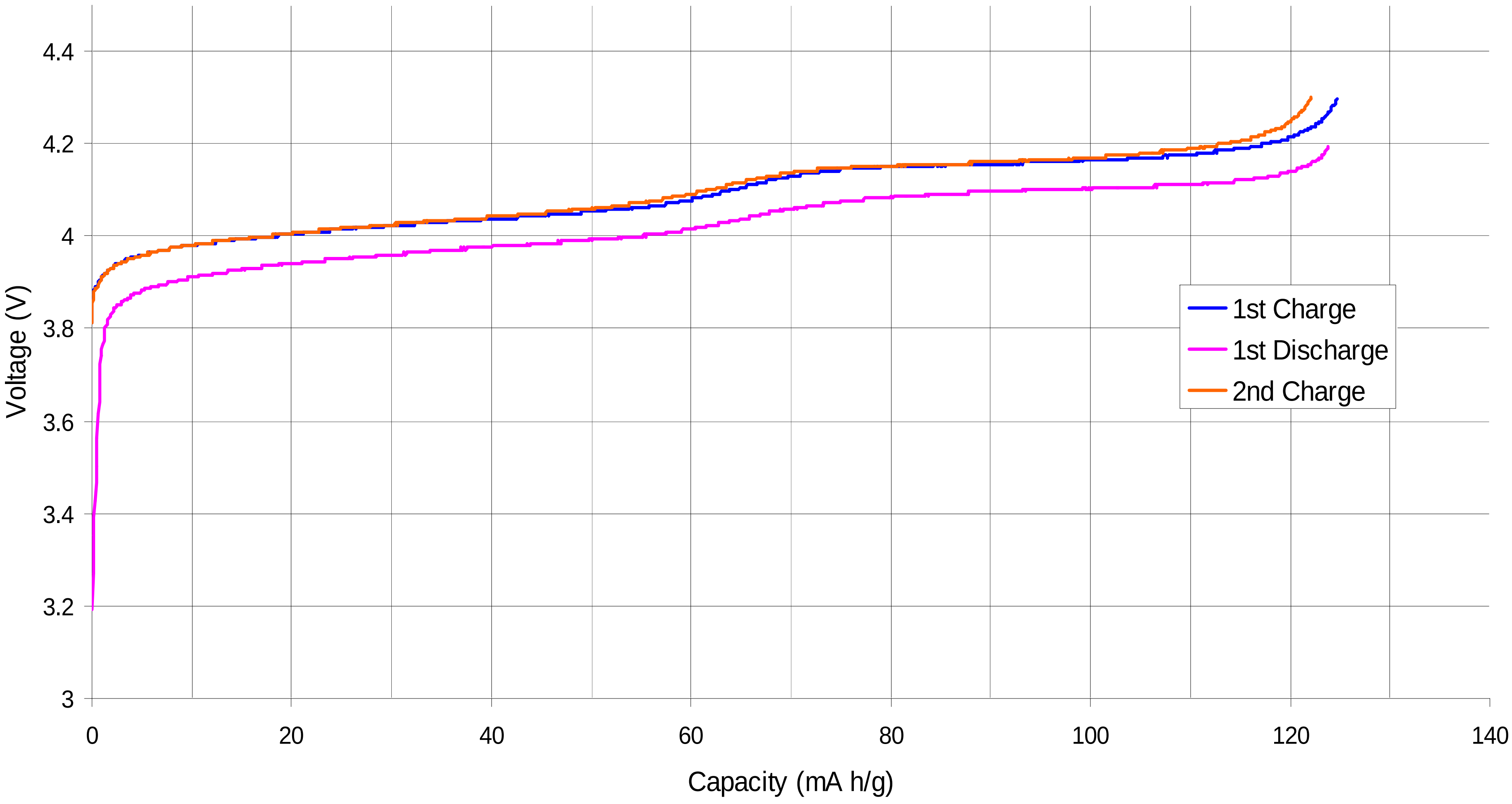
Store in oven 5 Days

4

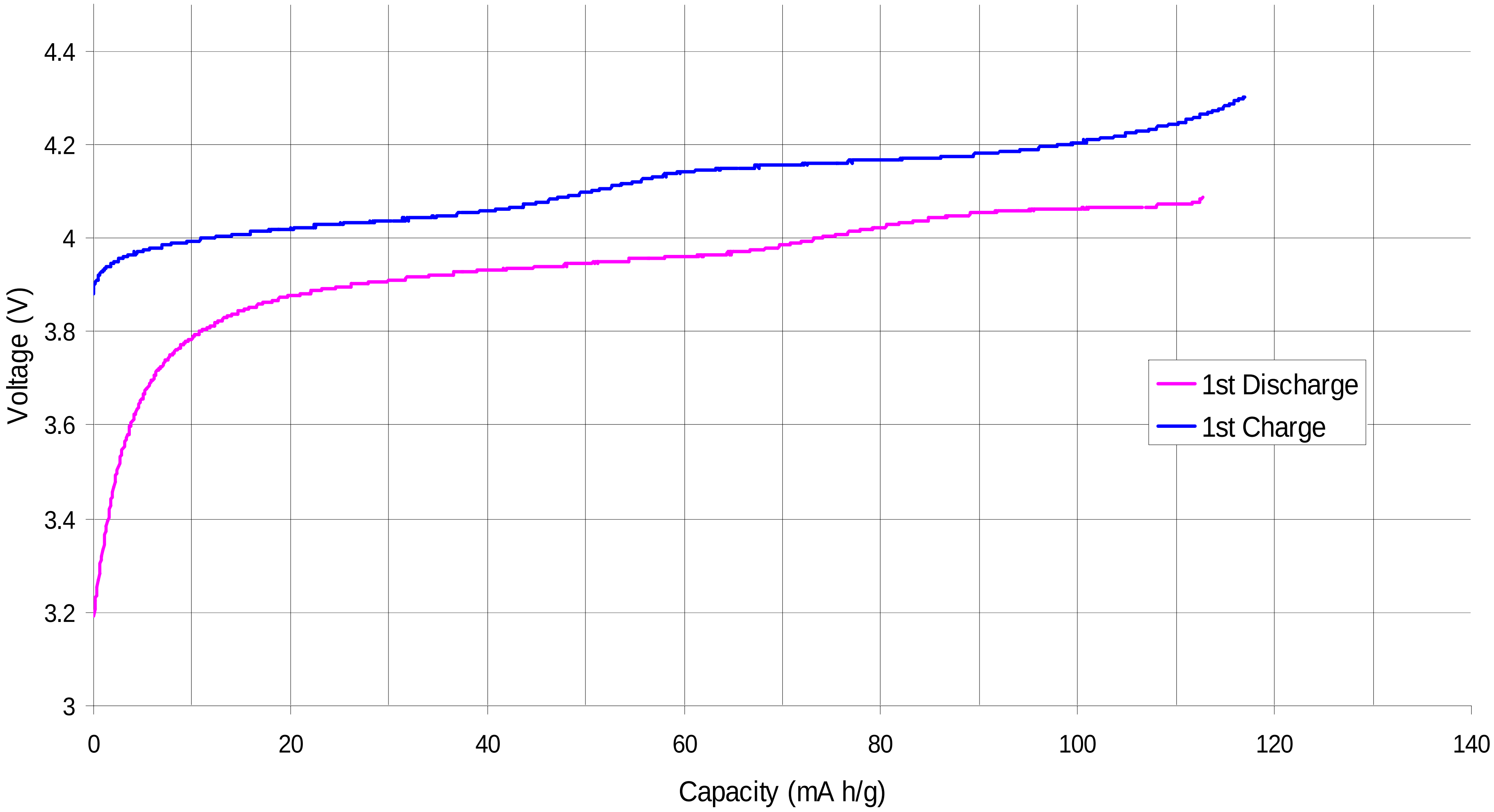


After Storage

Capacity Measurement of $LiMn_2O_4$ Before Storage



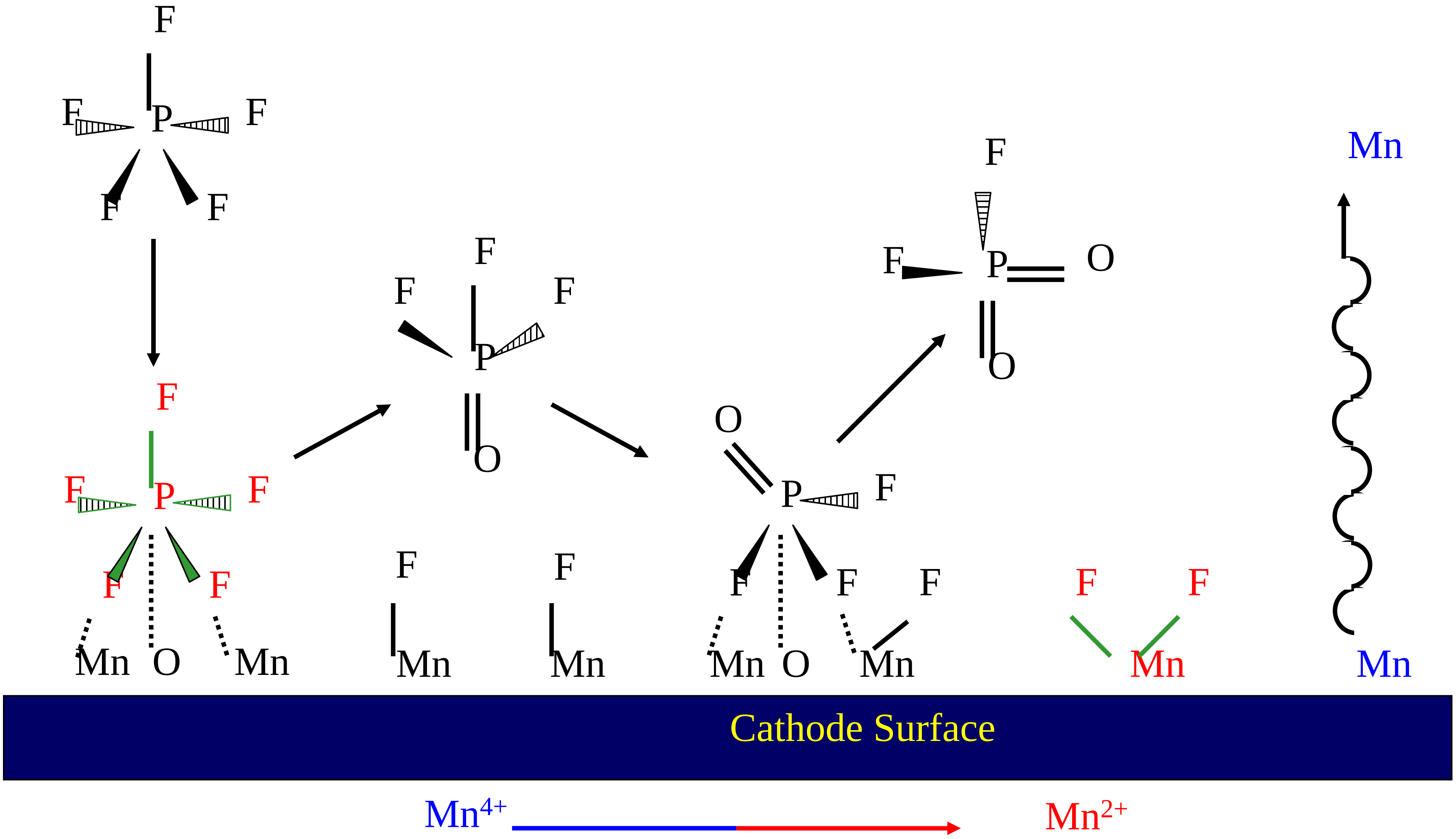
Degradation: Capacity Measurement of $LiMn_2O_4$ After Storage at 70 C



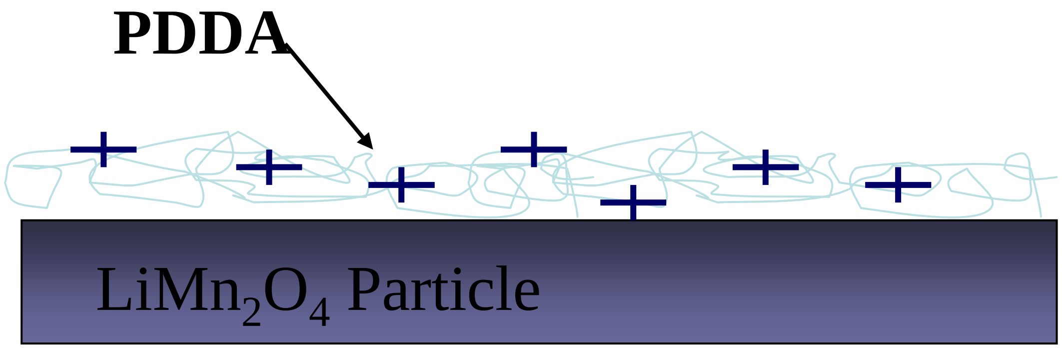
Proposed Surface and Solvent Degradation

F. Quinlan et al., Chem. Mat. 2002

$$LiPF_6 \rightleftharpoons LiF + PF_5$$



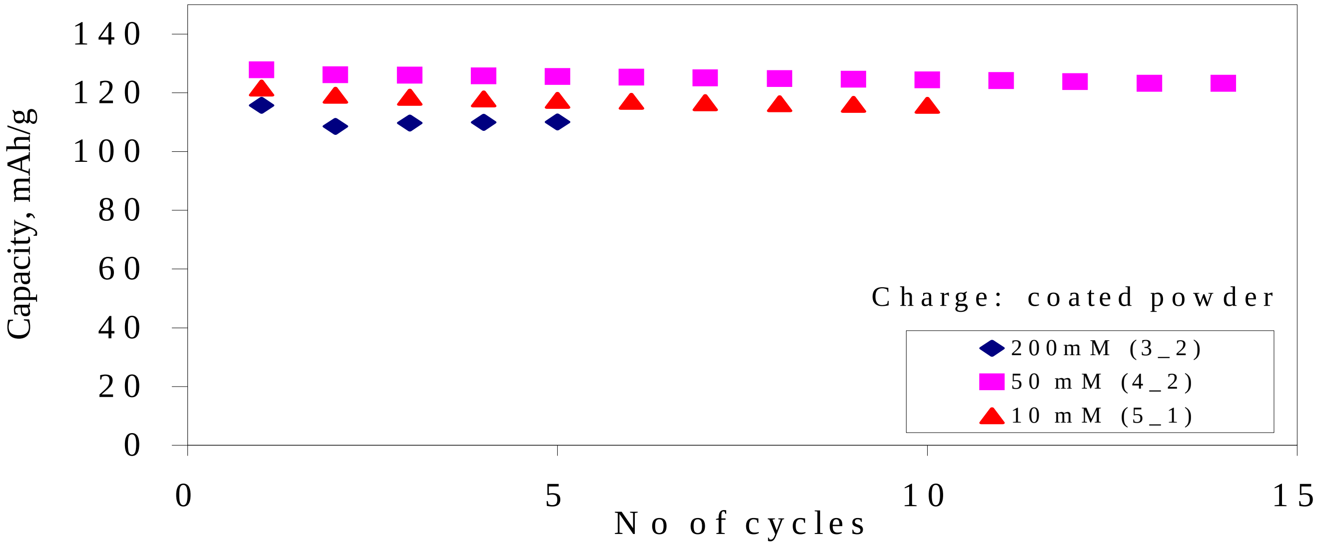
Surface coating (adsorption) with ~1 nm PDDA on $LiMn_2O_4$ to inhibit surface degradation

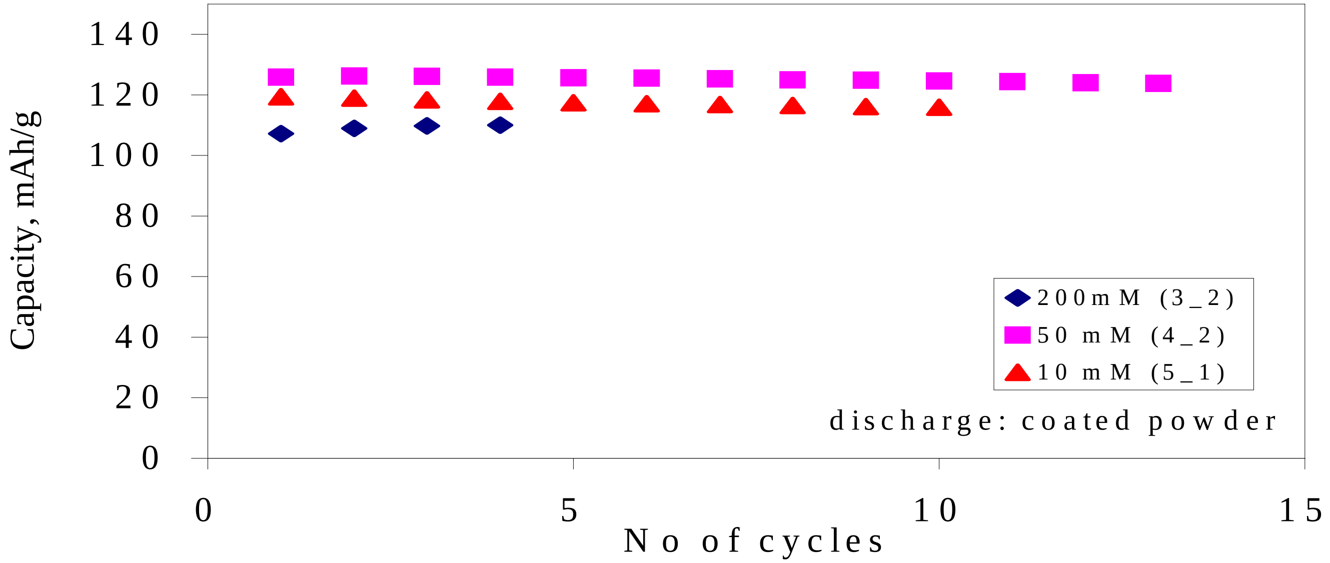


$LiMn_2O_4$ Particle

Treated cathodes show better capacity.

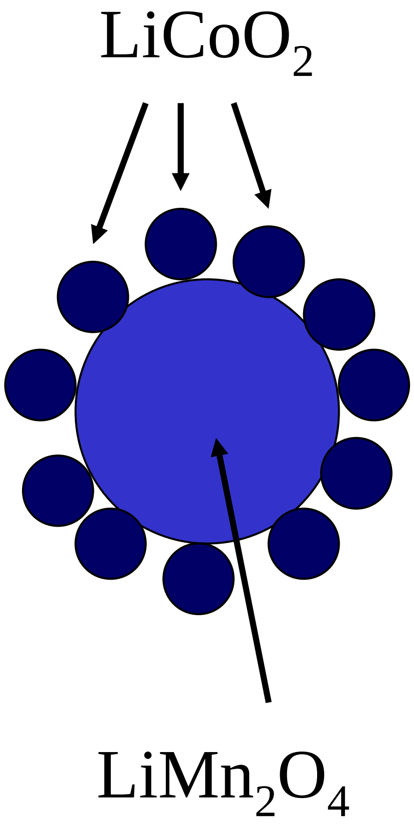
The variation of the measured capacity with the number of cycles for the cathodes obtained from the PDDA coated powder (Vidu and Stroeve, in press).





Another approach: coating $LiMn_2O_4$ powder with $LiCoO_2$ nanoparticles

- Objective – to stop surface degradation of the cathode material
- Use $LiCoO_2$ which does not degrade at elevated temperatures
- Protect the $LiMn_2O_4$ material with the $LiCoO_2$ coating



Why $LiCoO_2$ over $LiMn_2O_4$?

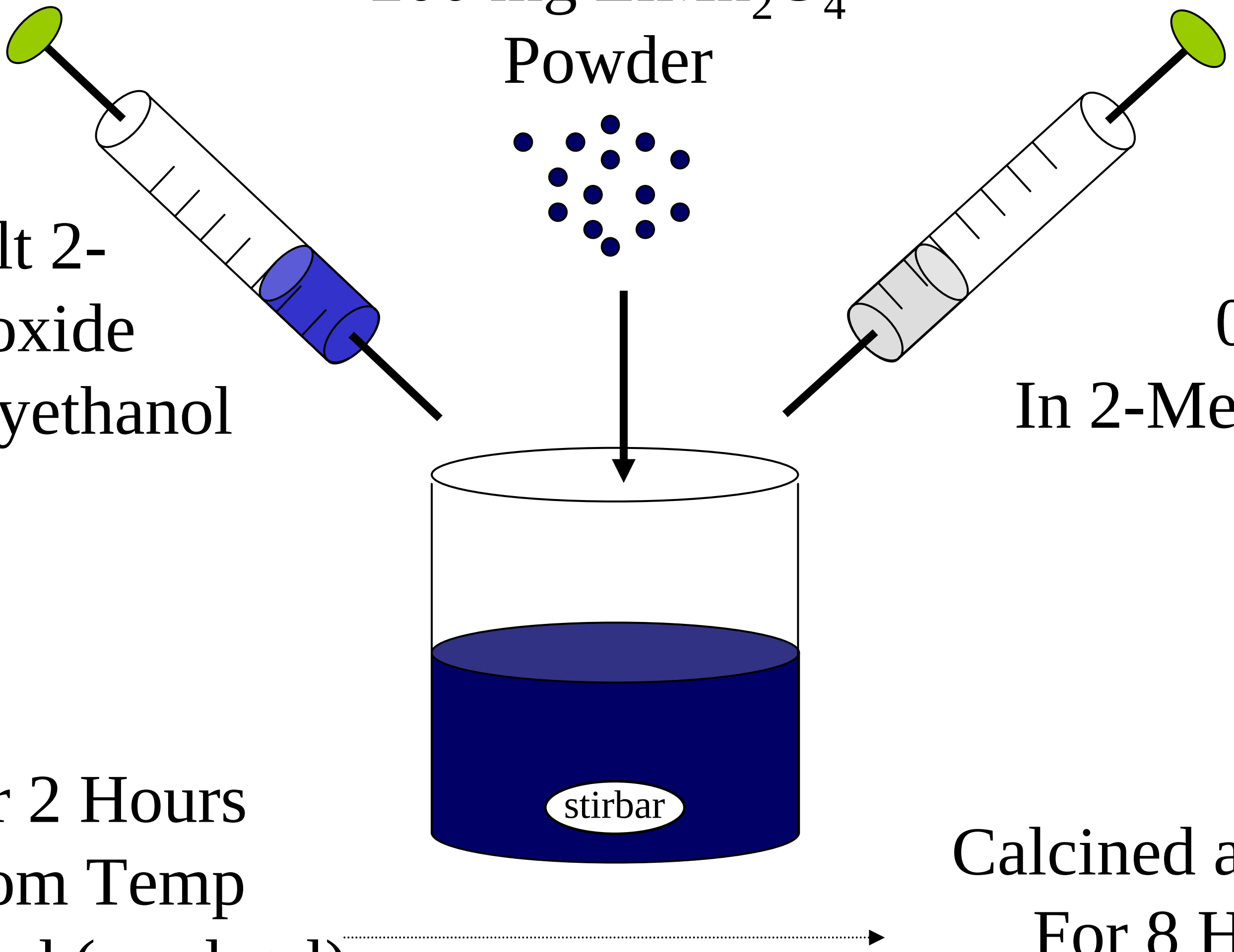
- No significant capacity fading of $LiCoO_2$ at elevated temperatures

Why $LiMn_2O_4$ over $LiCoO_2$?

- Less Toxic
- Less Expensive
- Easily synthesized

Coating of $LiMn_2O_4$ Powder With $LiCoO_2$ nanoparticles

F. Quinlan et al., submitted



200 mg $LiMn_2O_4$
Powder

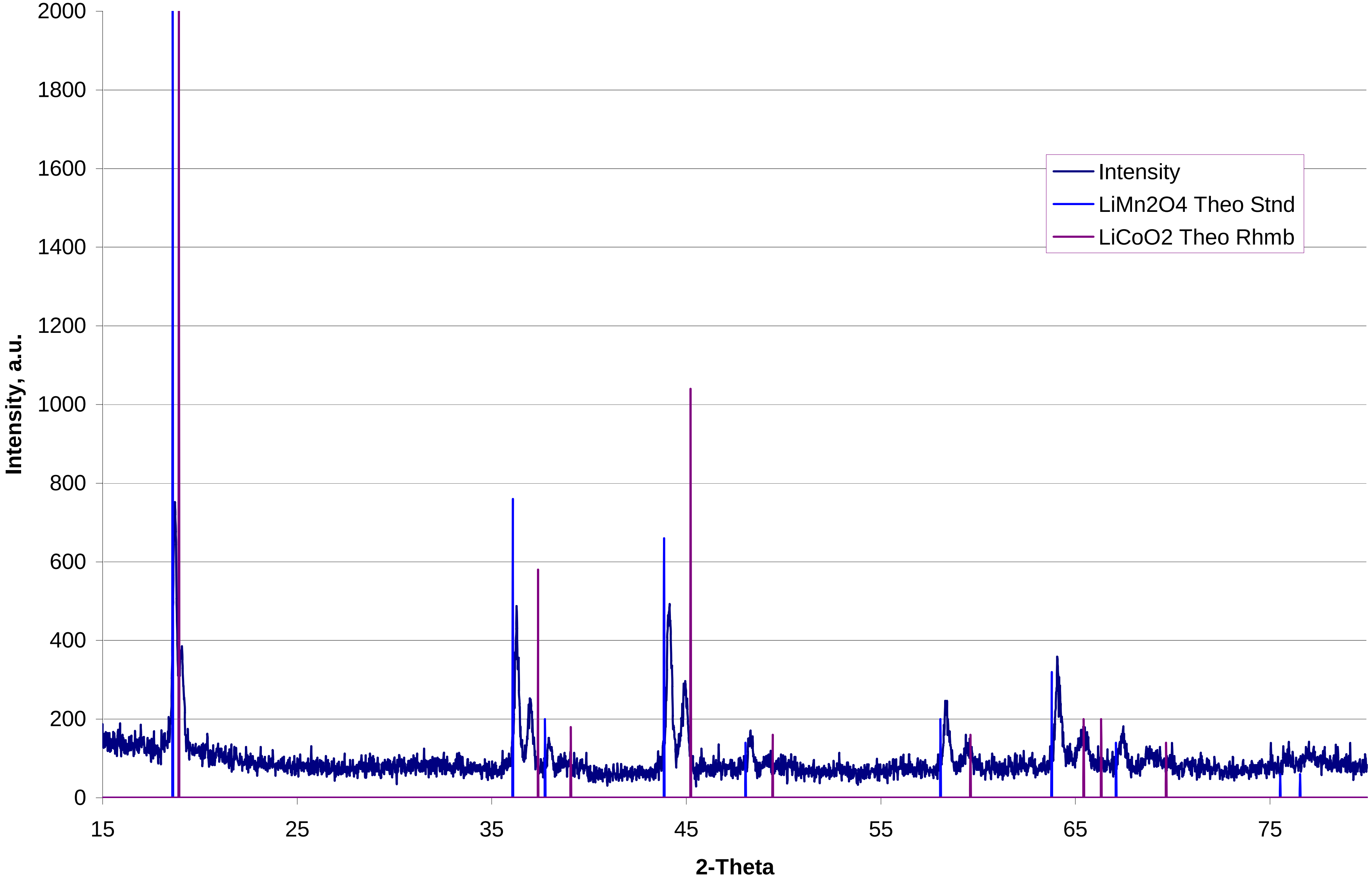
3 mL
0.23M Cobalt 2-Methoxyethoxide
In 2-Methoxyethanol

3 mL
0.23M $LiNO_3$
In 2-Methoxyethanol

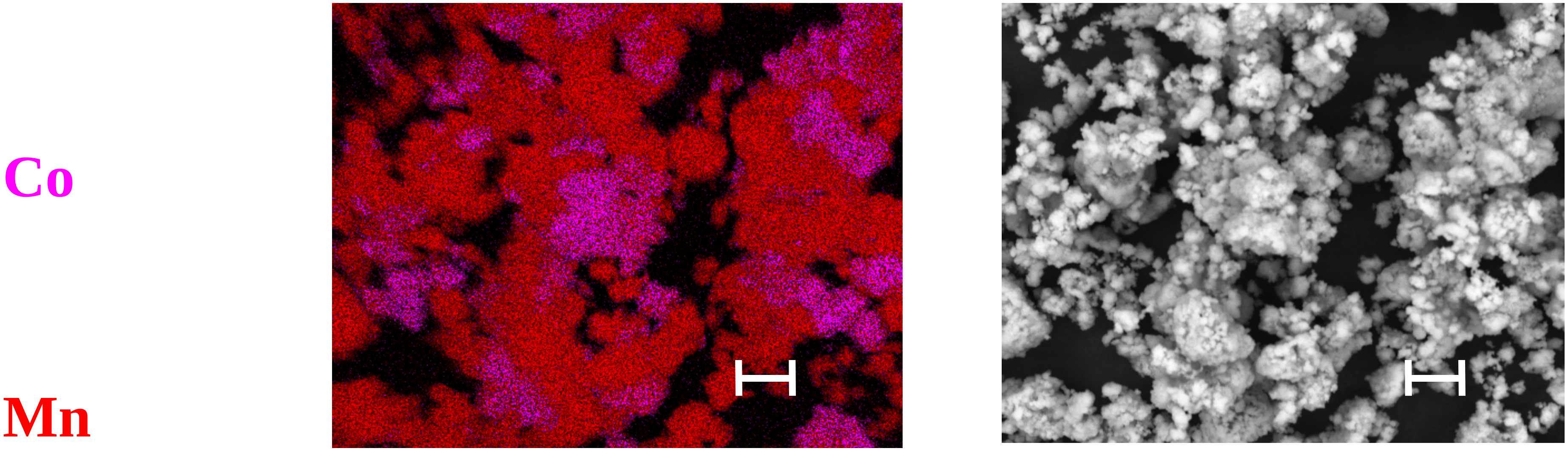
Stir for 2 Hours
At Room Temp
Until Gelled (a sol gel)

Calcined at 800 C
For 8 Hours

XRD of Coated $LiMn_2O_4$ Powder With $LiCoO_2$



SEM elemental mapping of coated Powder



SEM compositional mapping (left panel) of nanoparticles on $LiMn_2O_4$ powder particles with Mn shown in red and Co in pink. The SEM micrograph for the identical sample location is shown in the right panel. Nanoparticles are 100 nm.

Surface modification on the nanoscale can lead to large changes in the macroscopic behavior of systems. Surface modification can be done in a standard laboratory

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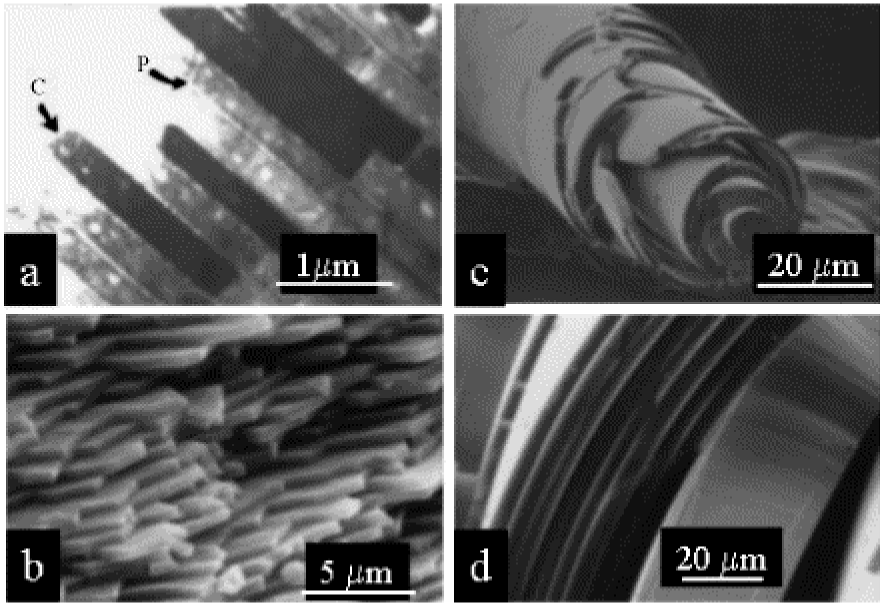
Biomaterial: biological mortar as a glue for composites

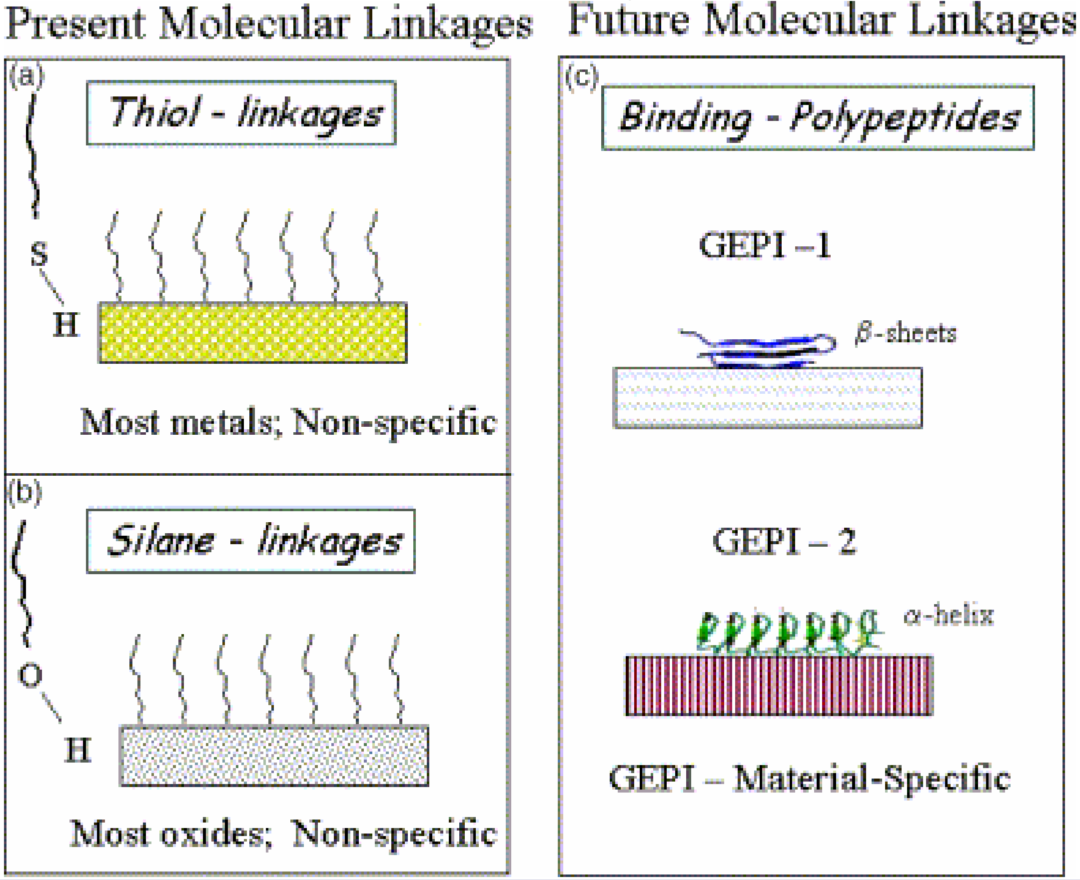
Peptide glue

Biological hard tissues: (a) TEM cross-section and (b) SEM fractured surface of nacre (mother-of-pearl) showing brick-mortar microarchitecture of the biocomposite, where the mortar is mostly composed of proteins. (c) and (d) SEM images of layered structure of sponge spicules in which layers are separated by an organic substance (M. Sarikaya).



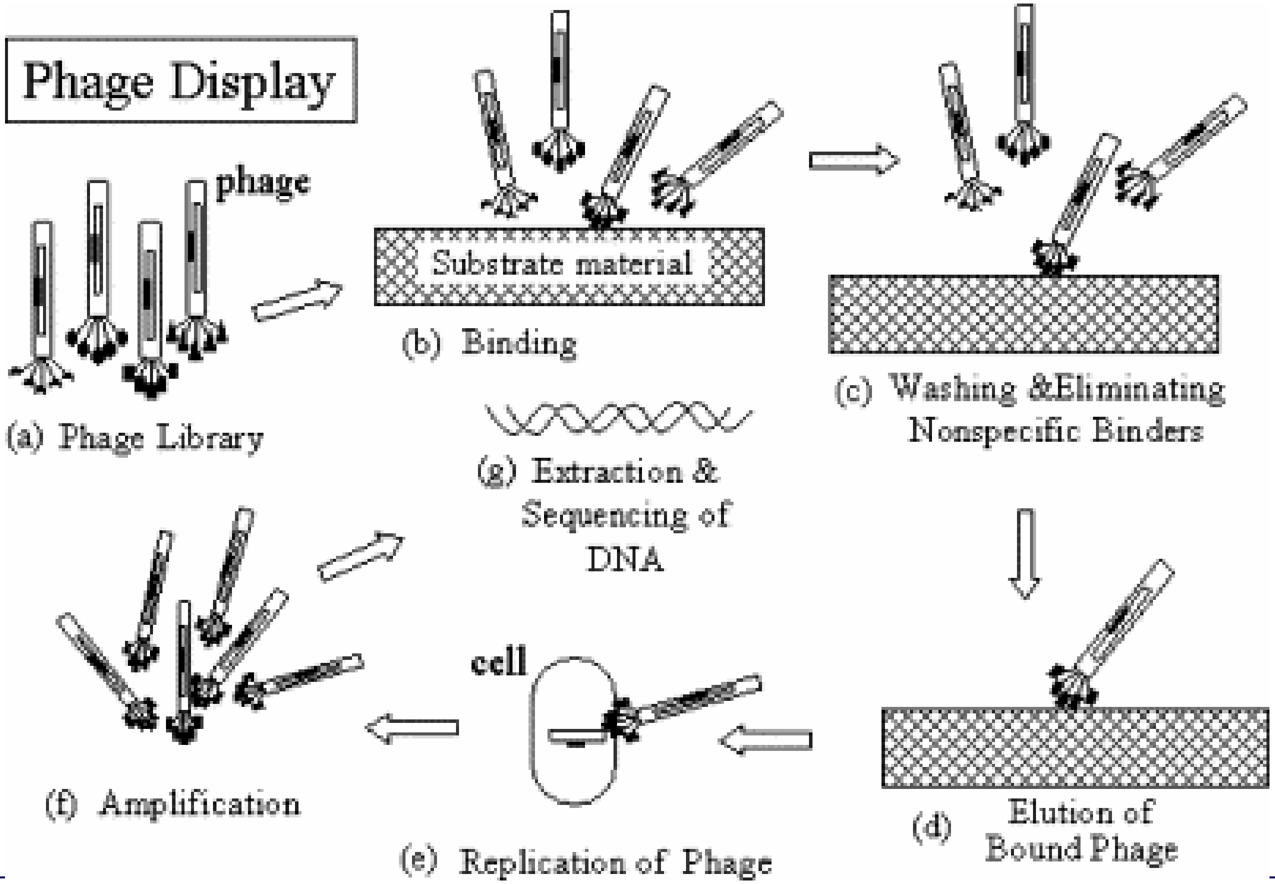
Biomimetic molecular coatings using engineered proteins

Thiol- and silane-based self-assembled monolayers are chemical linked onto noble metals or oxides, respectively. Engineered proteins could bind to a given material specifically. While (a) thiol- and (b) silane-linkages are non-specific, (c) genetically engineered polypeptides could be material specific with a variety of conformational architectures (M. Sarikaya).



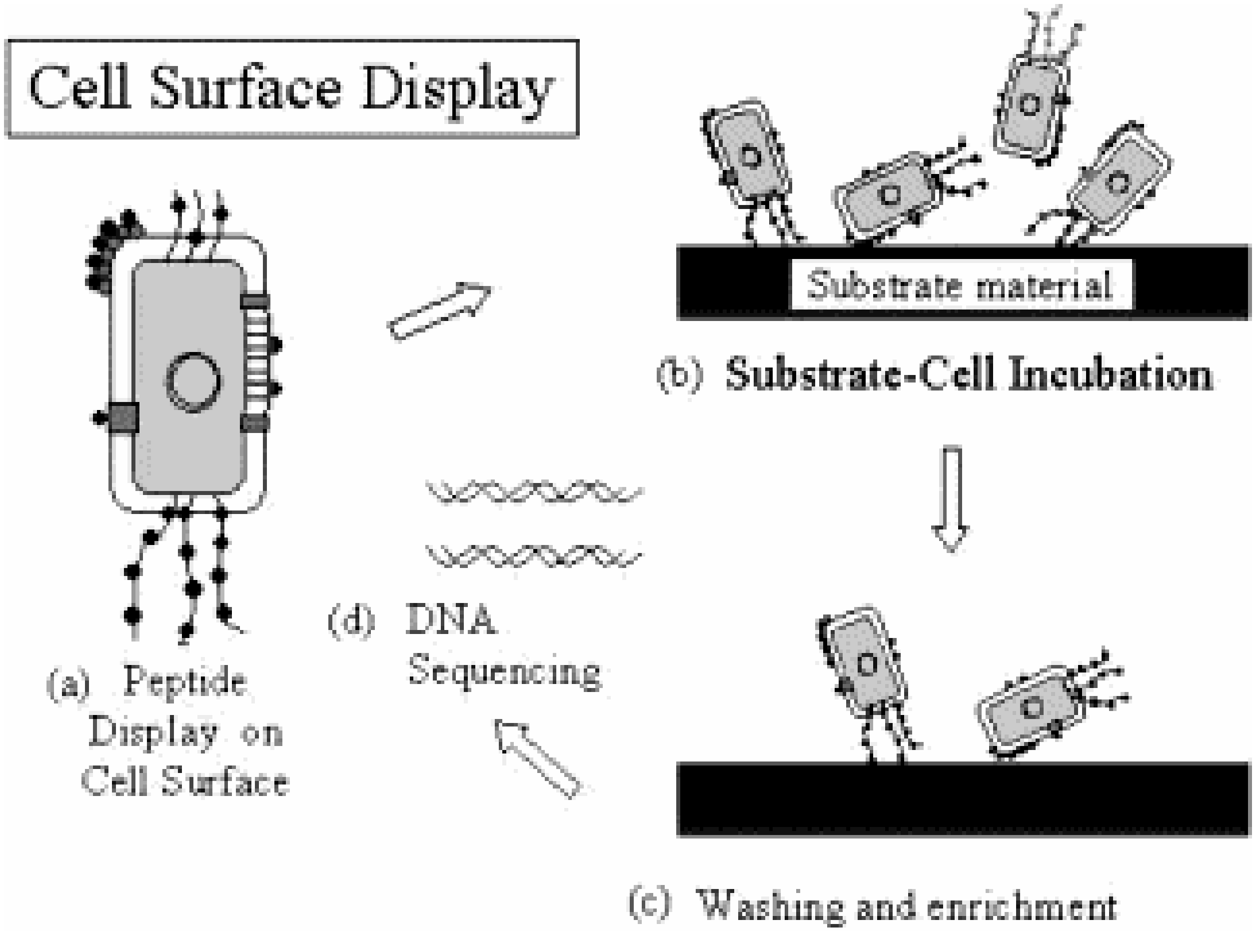
Biomimetic molecular coatings using engineered proteins

A flowchart of phage display protocol (from M. Sarikaya)

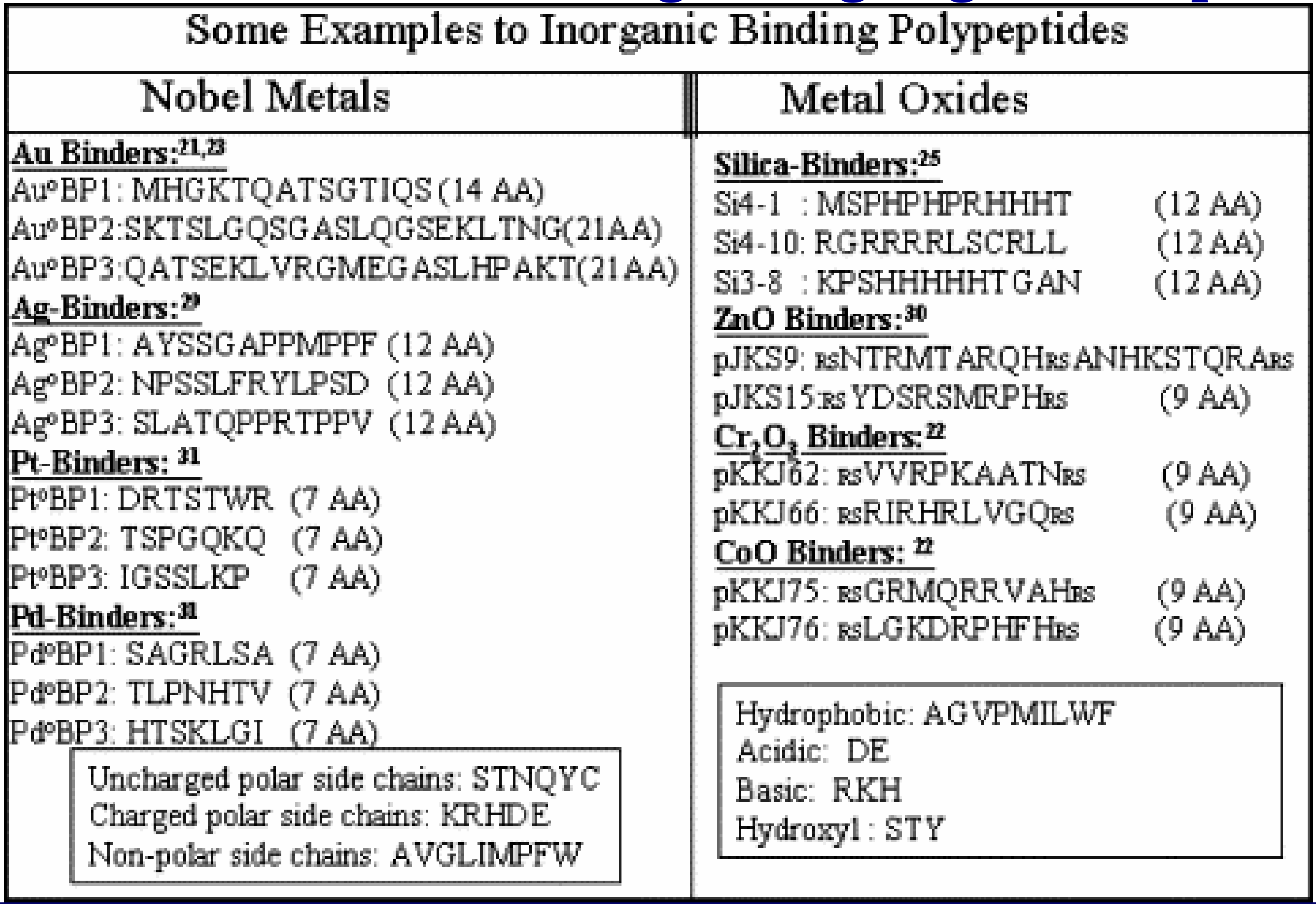


Biomimetic molecular coatings using engineered proteins

Flowchart of cell surface display protocol (from M. Sarikaya)



Biomimetic molecular coatings using engineered proteins



Some Examples to Inorganic Binding Polypeptides

Nobel Metals

Au Binders:[21,23]

Au°BP1: MHGKTQATSGTIQS (14 AA)
Au°BP2:SKTSLGQSGASLQGSEKLTNG(21AA)
Au°BP3:QATSEKLVRGMEGASLHPAKT(21AA)

Ag-Binders:[29]

Ag°BP1: AYSSGAPPMPPF (12 AA)
Ag°BP2: NPSSLFRYLPSD (12 AA)
Ag°BP3: SLATQPPRTPPV (12 AA)

Pt-Binders: [31]

Pt°BP1: DRTSTWR (7 AA)
Pt°BP2: TSPGQKQ (7 AA)
Pt°BP3: IGSSLKP (7 AA)

Pd-Binders:[31]

Pd°BP1: SAGRLSA (7 AA)
Pd°BP2: TLPNHTV (7 AA)
Pd°BP3: HTSKLGI (7 AA)

Uncharged polar side chains: STNQYC
Charged polar side chains: KRHDE
Non-polar side chains: AVGLIMPFW

Metal Oxides

Silica-Binders:[25]

Si4-1 : MSPHPHPRHHHT (12 AA)
Si4-10: RGRRRRLSCRLL (12 AA)
Si3-8 : KPSHHHHHTGAN (12 AA)

ZnO Binders:[30]

pJKS9: RSNTRMTARQHRSANHKSTQRARS
pJKS15:RSYDSRSMRPHRS (9 AA)

Cr_2O_3 Binders:[22]

pKKJ62: RSVVRPKAATNRS (9 AA)
pKKJ66: RSRIRHRLVGQRS (9 AA)

CoO Binders: [22]

pKKJ75: RSGRMQRRVAHRS (9 AA)
pKKJ76: RSLGKDRPHFHRS (9 AA)

Hydrophobic: AGVPMILWF
Acidic: DE
Basic: RKH
Hydroxyl : STY

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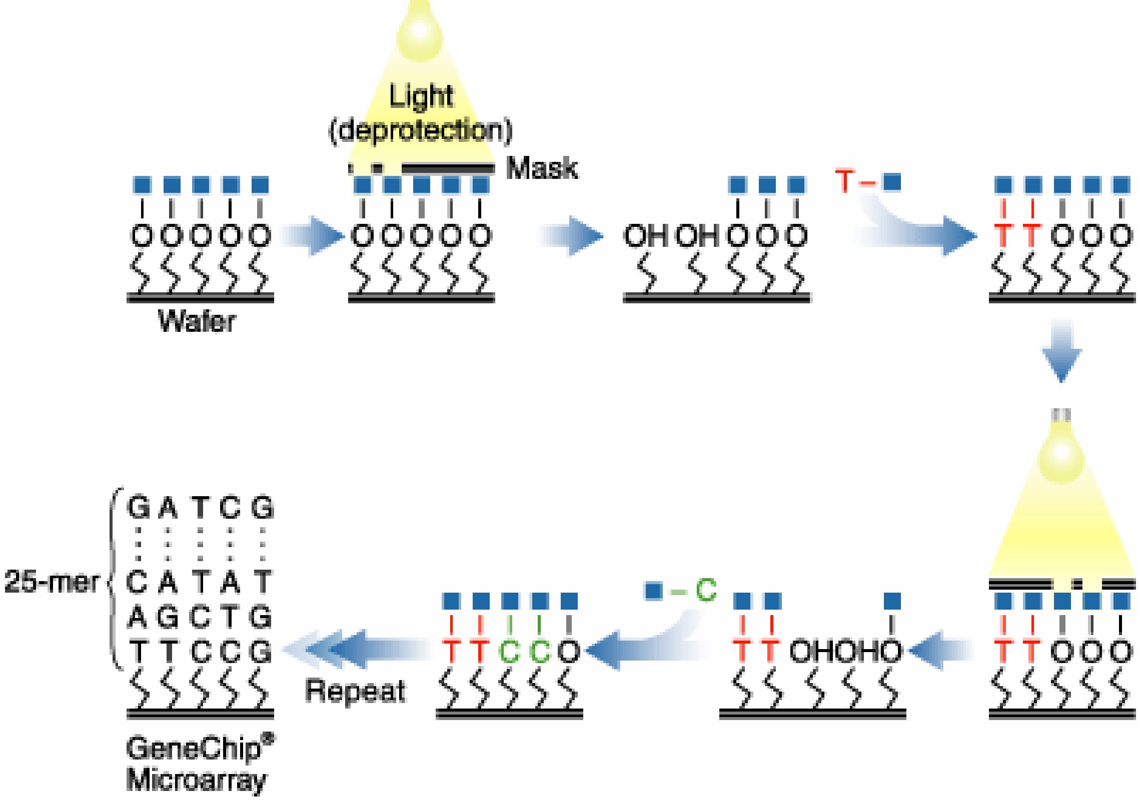
Nanotechnology in the life sciences

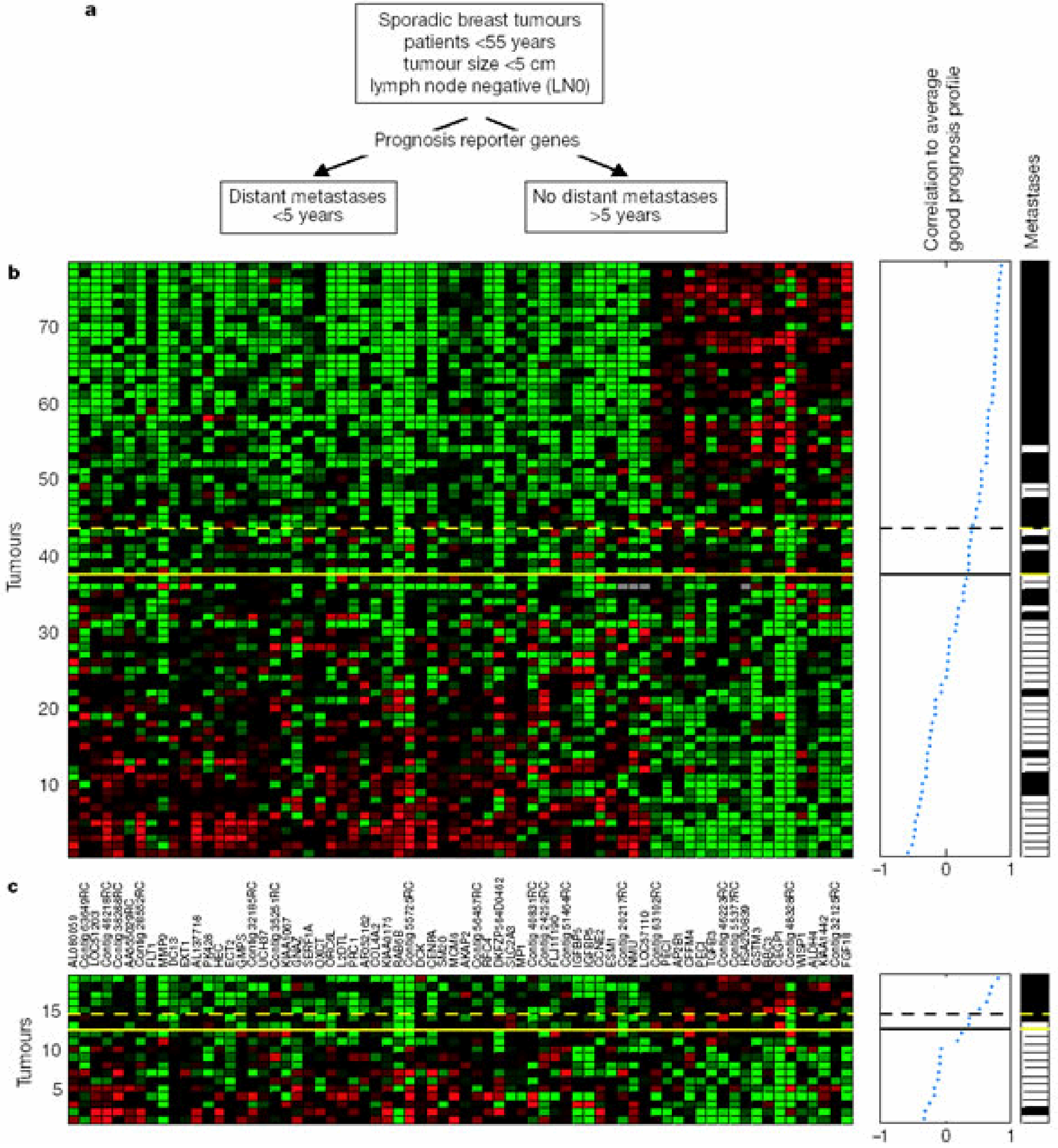
Affymetrix GeneChip® Arrays

Affymetrix uses a unique combination of photolithography and combinatorial chemistry to manufacture GeneChip® Arrays



Gene expression profiling predicts clinical outcome of breast cancer. Data from 78 tumors and 70 genes.

Nature **415**, 530 - 536 (31 Jan 2002)



Nanotechnology: (bio)materials

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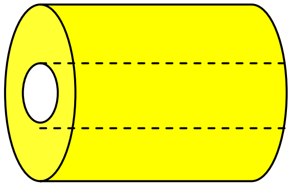
Nanowires, nanotubes, nanocables

Nanowires

Material: Cu, Fe, CdTe….

Applications: electronic devices, FED

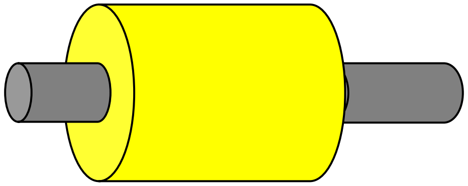
Nanotubes



Material: C, Au, Polymer….

Applications: biosensor, FED

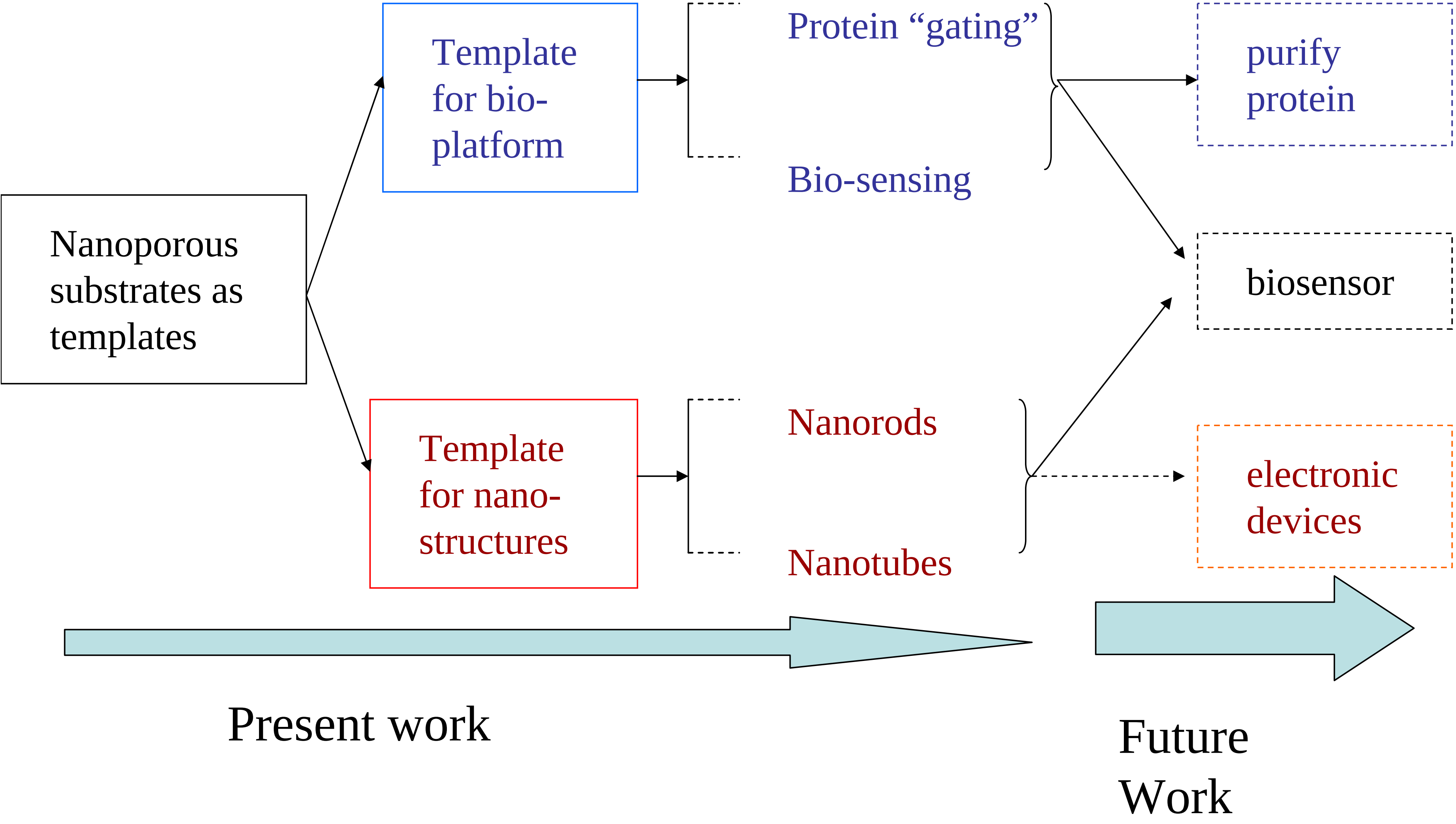
Nanocables



Materials: Ag/SiO_2, Zn/ZnS

Applications: electronic devices

Nanotubes



Nanoporous substrates as templates

Template for bio-platform

Protein "gating"

Bio-sensing

Template for nano-structures

Nanorods

Nanotubes

purify protein

biosensor

electronic devices

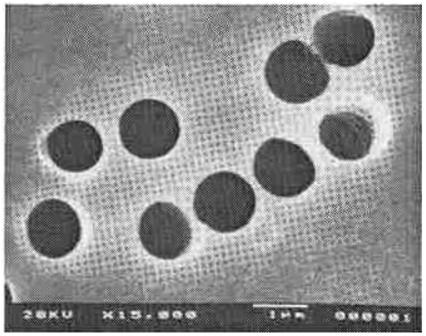
Present work

Future Work

Nanoporous Substrates

1. **PCTE** (Polycarbonate track-etching membranes)

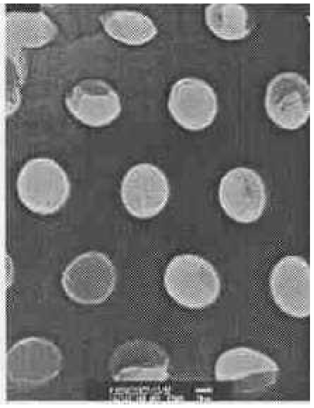
- Mono-disperse pore and narrow pore size distribution
- Random distribution
- Uniform diameters (10 nm ~ 20 μm, commercially available)
- Pore density ~ 10^9 pore/cm^2



SEM image of PCTE membrane with 1 um diameter pores. Ref: J. C. Hulteen and C. R. Martin, *J. Mater. Chem.*, 1997 **7(**7), 1075.

2. **AAO** (Anodic Aluminum Oxide membranes)

- Mono-disperse pore and narrow pore size distribution
- Hexagonal array
- Uniform diameters (limited pore size, commercially available)
- Pore density ~ 10^{11} pore/cm^2



TEM image of AAO membrane with 70 nm diameter pores. Ref: J. C. Hulteen and C. R. Martin, *J. Mater. Chem.*, 1997 **7(7),** 1075.

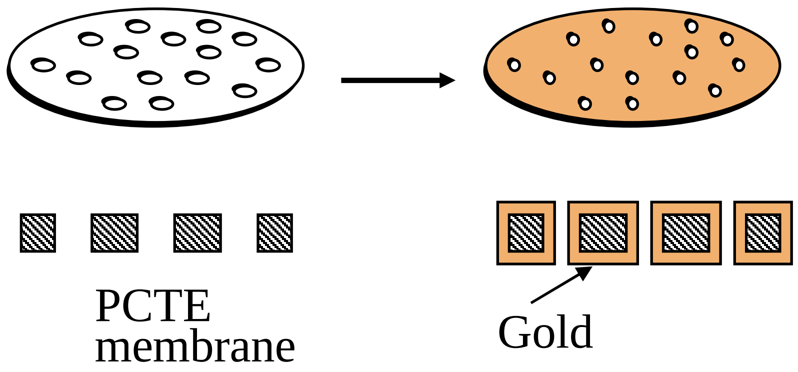
3. Porous silicon

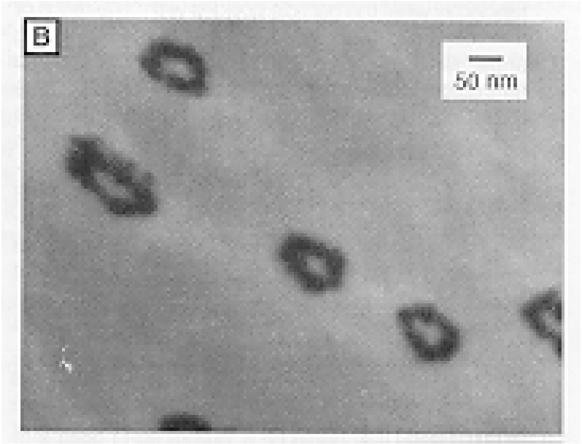
- 20 nm uniform pores

Electroless Deposition:
A Technique to Deposit Metals on Complex Surfaces

Nishizawa et al., *Science*, 1995:

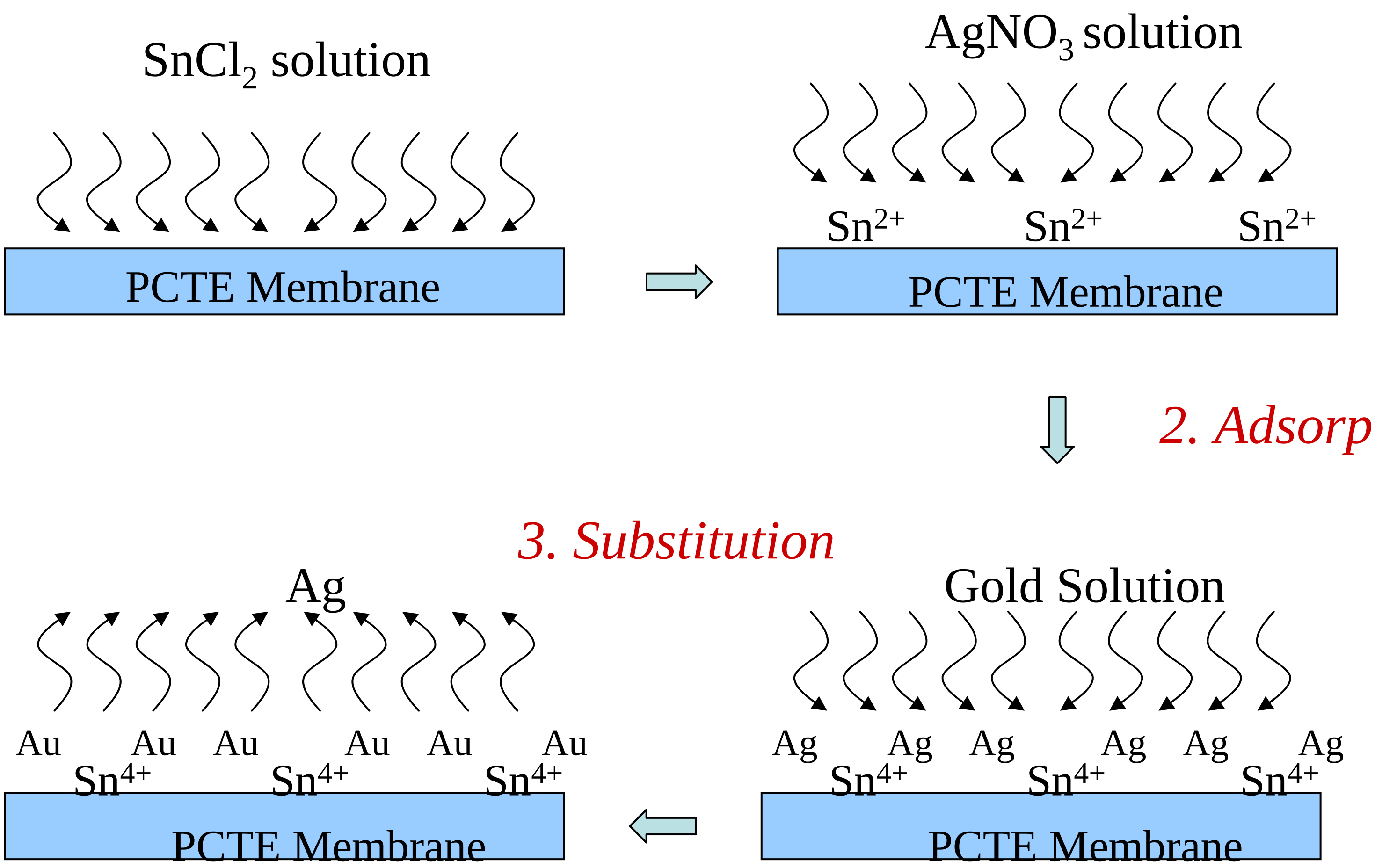
Electroless gold deposition in polycarbonate track-etched (PCTE) membranes





Charge-selectivity can be reversibly controlled by electrical potentials applied to gold

Procedure of Electroless Gold Plating on PCTE Membranes



1. Sensitization

$SnCl_2$ solution

PCTE Membrane

$AgNO_3$ solution

Sn^{2+} Sn^{2+} Sn^{2+}

PCTE Membrane

2. Adsorption

Gold Solution

Ag Ag Ag Ag Ag Ag

Sn^{4+} Sn^{4+} Sn^{4+}

PCTE Membrane

3. Substitution

Ag

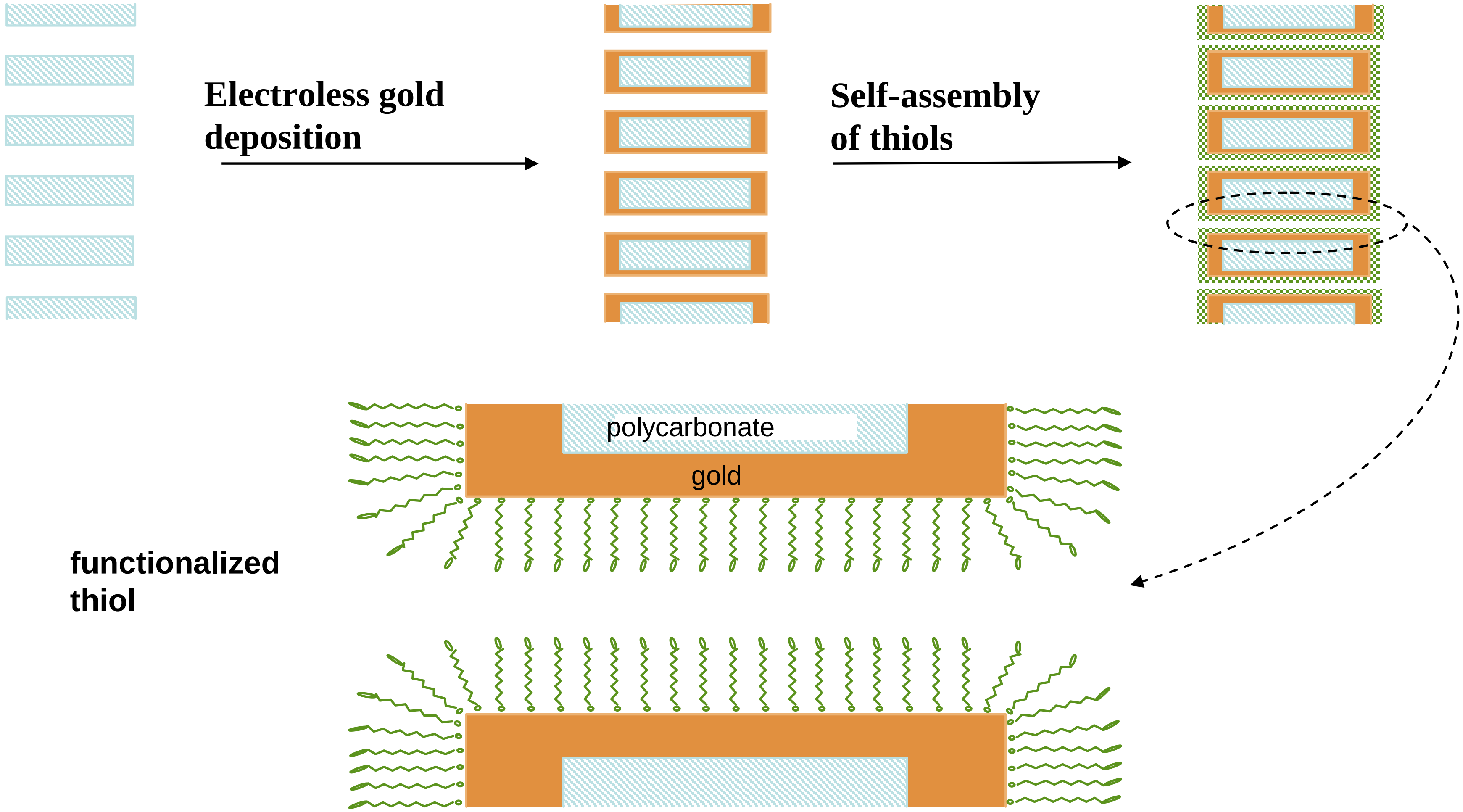
Au Au Au Au Au Au

Sn^{4+} Sn^{4+} Sn^{4+}

PCTE Membrane

Requirements : Control the pH(10~10.5) and temperature (~1°C) in the gold solution

Modification of PCTE Membranes



Electroless gold deposition

Self-assembly of thiols

functionalized thiol

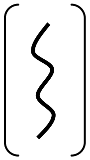
Pore radii of bare PCTE membranes: 12 - 28 nm

Pore radii of after gold deposition: 4 - 15 nm

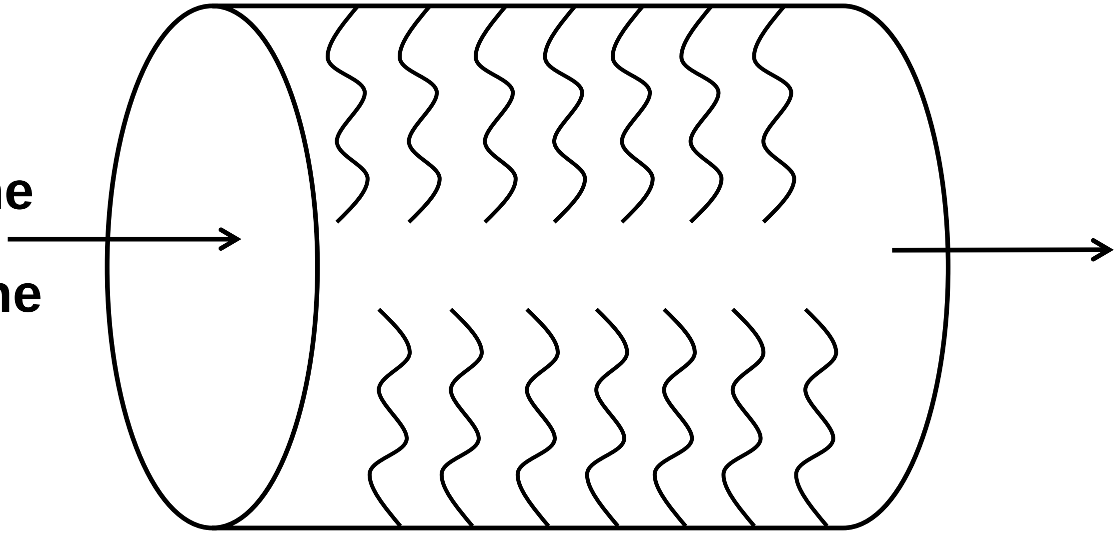
Hou & Stroeve, Langmuir 2000; Chun & Stroeve, Langmuir 2001, 2002; Ku & Stroeve Langmuir 2004

Functionalized nanotubes with alkane thiol chains enables separation of hydrophobic from hydrophilic species

C_3, C_{10} and C_{16} } alkane thiols



C. Martin, U of Florida



toluene
+
pyridine

toluene flux = 165 X pyridine flux
(2.0 nm tubes)

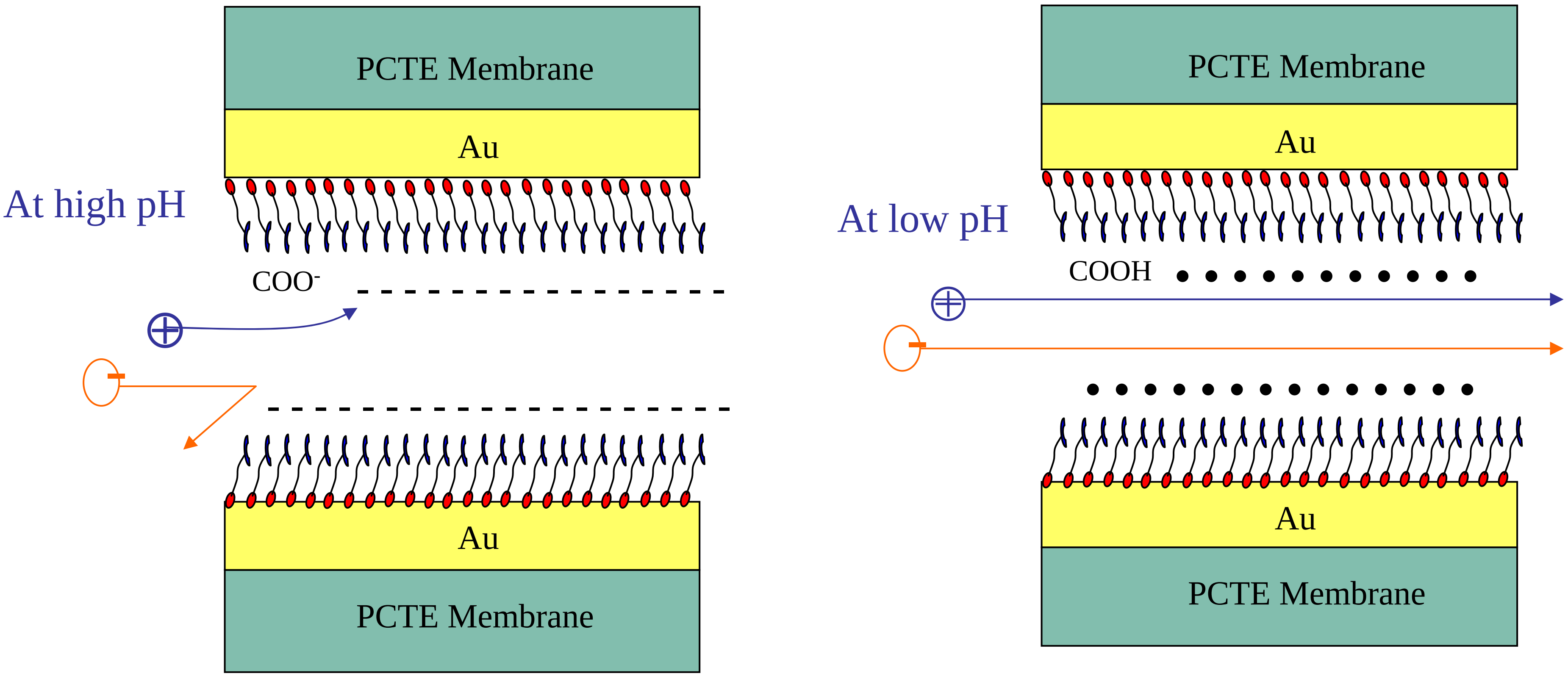
Factor of 15 X for 3.0 nm tubes

toluene: hydrophobic

pyridine: hydrophilic

Transport Mechanism - General Idea

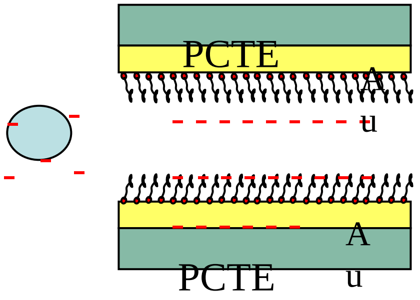
pH-Responsive Nanomembranes



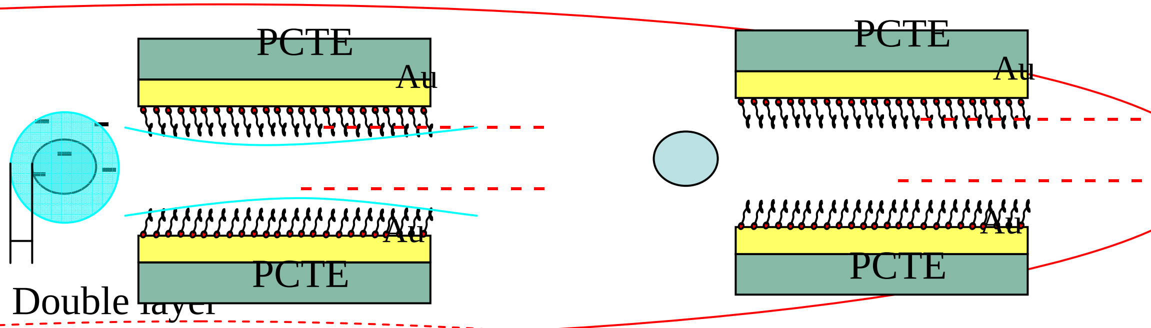
External control factors

External Control Factors

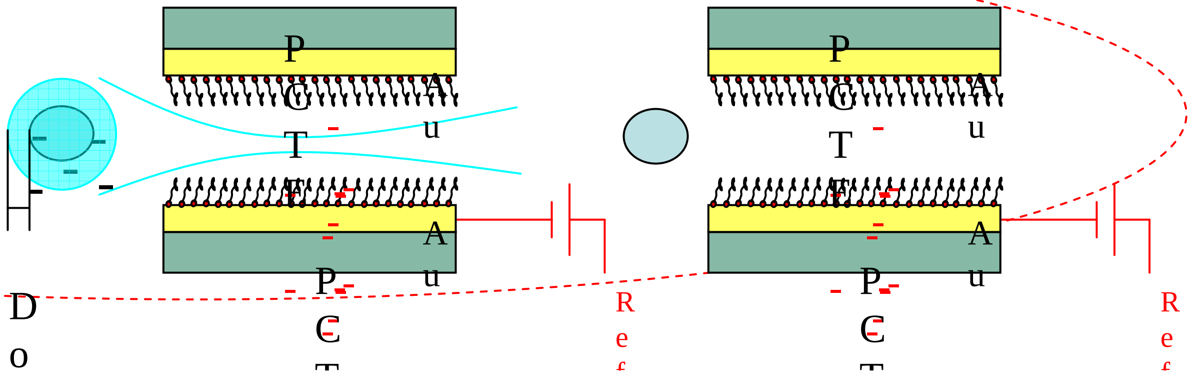
1. pH (Ref.:K. Y. Chun and P. Stroeve, Langmuir, 18, 4653-4658, 2002)



2. Ionic Strength (Debye length)



3. Applied Potential

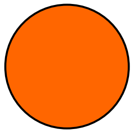


pH responsive nanoporous membranes for protein Separation: proteins with similar molecular size and weight

Chung, Ku, Stroeve in Langmuir, 2002, 2004

BHb (Bovine Hemoglobin)

Spherical



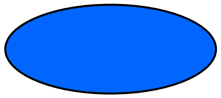
6.4 x 5.5 x 5 nm

Molecular weight = 65 kD

pI = 7.0

BSA (Bovine Serum Albumin)

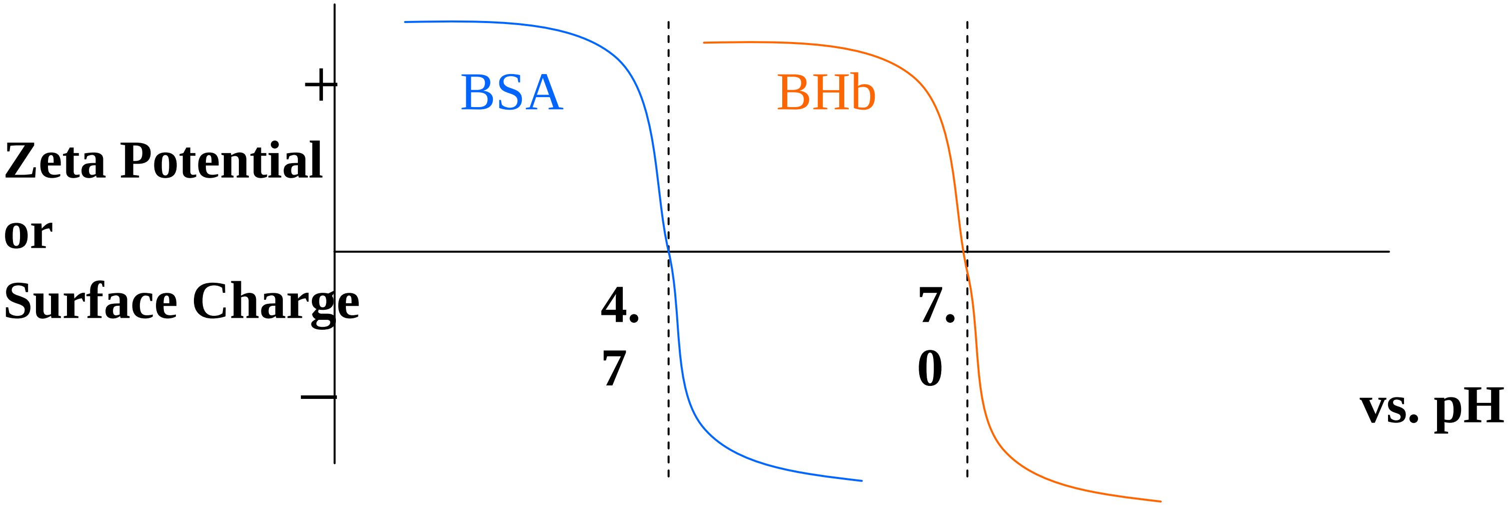
Globular ellipsoid



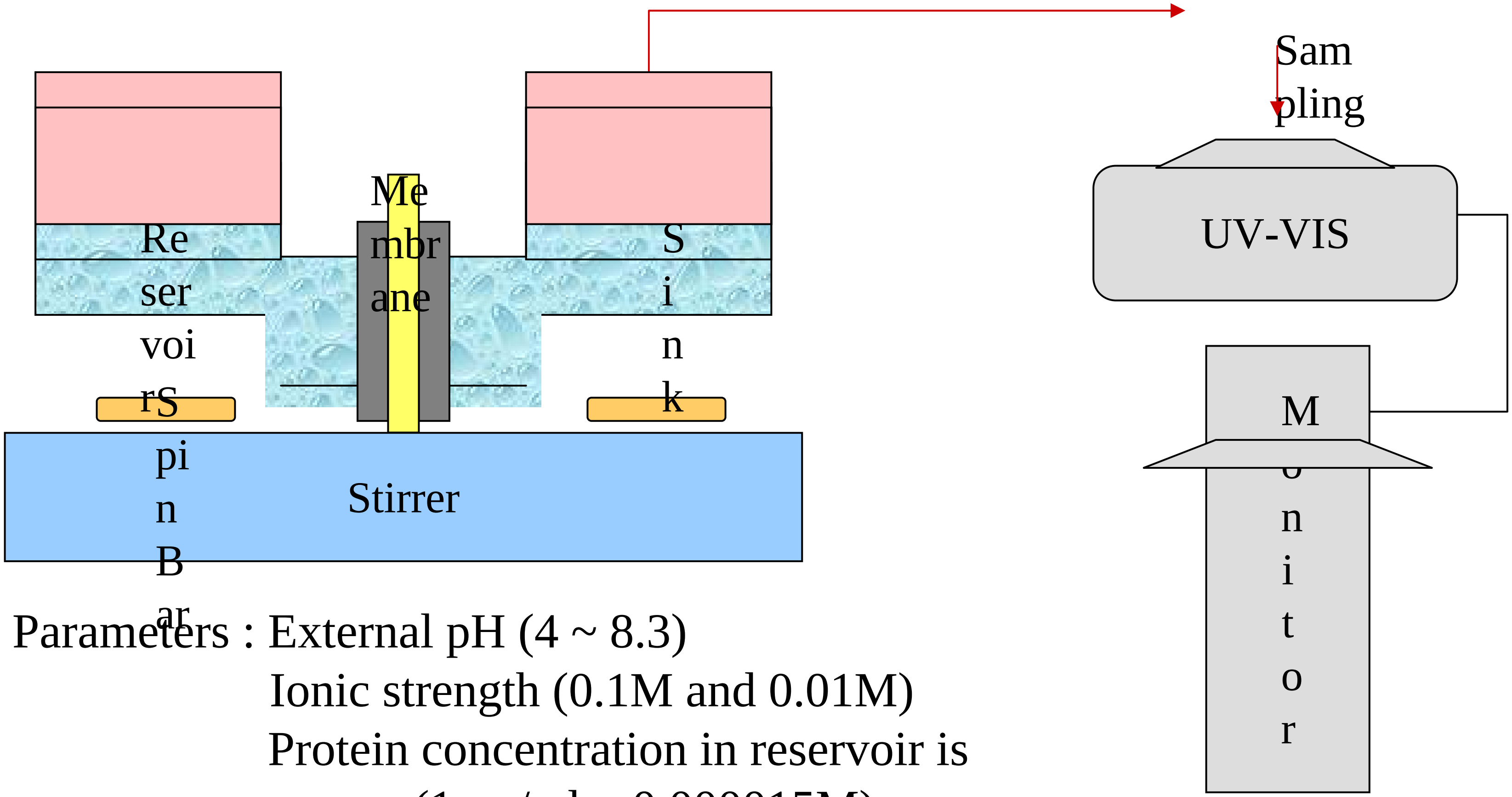
14 x 3.8 x 3.8 nm

Molecular weight = 66 kD

pI = 4.7

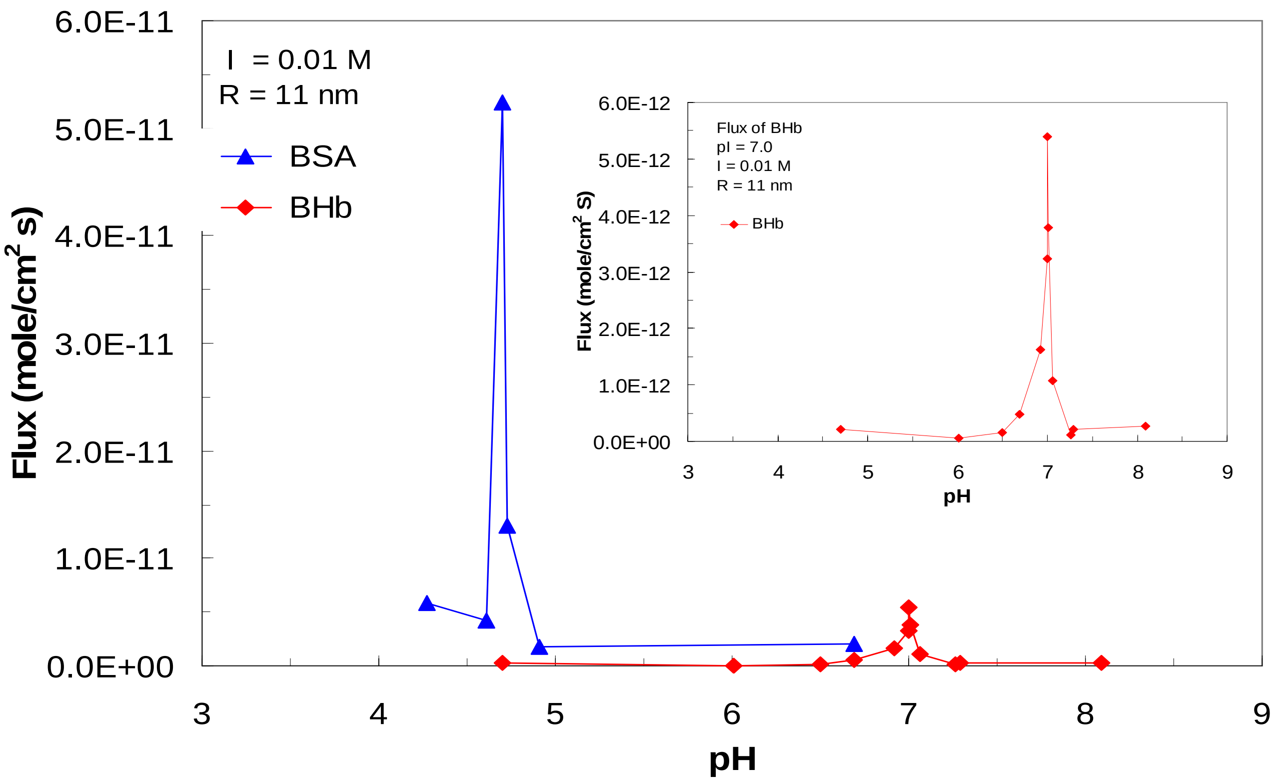


Experiment Set-up - Diffusion Measurement



Parameters : External pH (4 ~ 8.3)
Ionic strength (0.1M and 0.01M)
Protein concentration in reservoir is
(1mg/ml ~ 0.000015M)

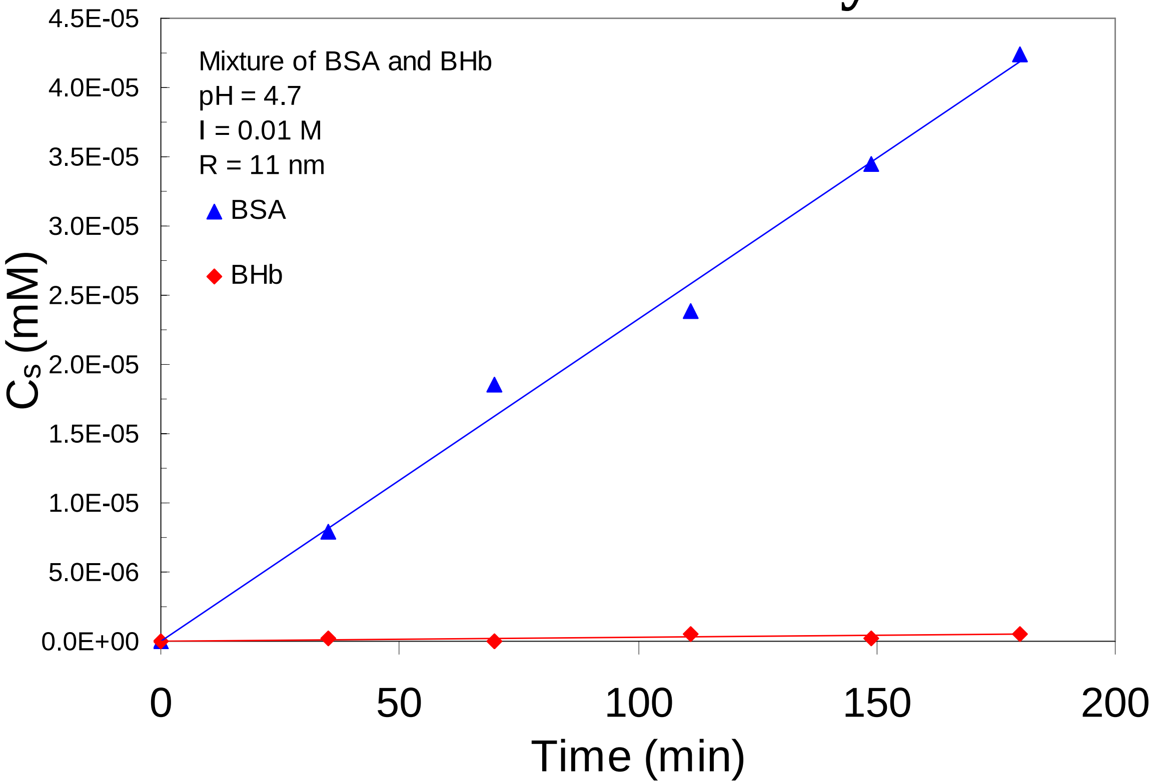
Low ionic strength, I= 0.01 M, shows “molecular gating phenomena” at pI



Comparison of fluxes versus pH for single BSA and single BHb transport experiments for I= 0.01 M. The insert shows the enlarged BHb results. Ku and Stroeve, Langmuir, 2004

Mixture of BHb+BSA at low ionic strength and pI of BSA

The BSA/BHb selectivity > 67.



Sink concentrations versus time for a mixture of BSA and BHb at pH = 4.7, I = 0.01 M, R= 11 nm. **Ku and Stroeve, Langmuir 2004.**

Protein transport in nanoporous membranes

- At low ionic strength, protein transport occurs mainly at the pI of the protein leading to a pseudo “molecular gating effect”.
- The selectivity of BSA over BHb is improved at the pI of BSA when the buffer solution is at a low ionic strength.

Nanotechnology in the life sciences: (bio)materials

Closing comments:

Nanotechnology has produced new materials with interesting properties. Nano-materials offer unique applications in biology. Surfaces play a dominant role in nanosystems.