Introduction to Nanoscience & Molecular Engineering (NME)

René M. Overney
Department of Chemical Engineering
University of Washington
Seattle, Washington 98195

roverney@u.washington.edu
http://depts.washington.edu/nanolab/

Birth of Interfacial and Molecular Sciences

- Colloid Science (early 1800s)

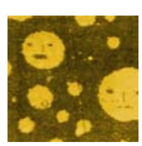
Products:
Aerosols of liquid droplets or solid particles
Foams
Emulsions
Sols or suspensions
Solid foams, emulsions or suspensions

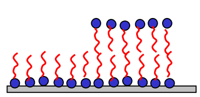
Micelle
a surfactant aggregate

Thomas Graham

- Surface Science (early 1900s)

Sub-disciplines:
Surface Chemistry
Surface Physics
Analytical Techniques



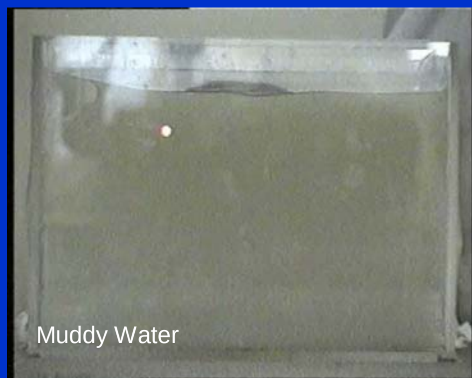


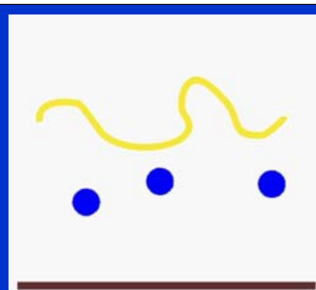
Irvin Langmuir &
Katharine Blodgett

Colloidal Process: Flocculation

Water Purification: 1) Addition of calcium chloride and flocculation agent
2) Initiation via shear

Flocculation of a clay suspension





bridging flocculation

Commercial flocculant:
polyacrylamide-*random*-(acrylic acid) copolymer

Bob Gilbert (University of Sydney, Australia)

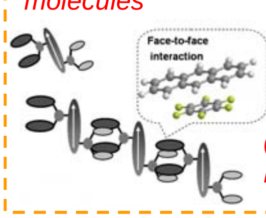
Functional Materials

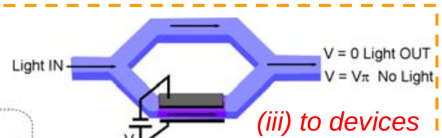
With increasing sophistication in molecular synthesis, material could be designed from the "bottom-up" for specific applications. → *Functional Materials*

Definition: Materials of rational molecular design tailored towards specific

- electronic
- magnetic
- optical
- thermal
- mechanical

(i) from macro-molecules





(iii) to devices

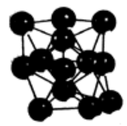
Electro-Optical (E-O) Switches

(ii) with unique structures and Properties if "assembled"

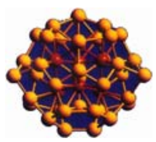
or other properties, to attain performance matrices that are/were conventionally unattainable are referred to as functional materials.

Bottom-up Approach

Inorganic material synthesis from atoms by means of “atomistic self-assembly”.



Si_{13}



Si_{45}

U. Rothlisberger, et al., Phys. Rev. Lett. **72**, 665 (1994).

- ***Molecule***:

  Ultra-small clusters: 10 – 100 atoms show strongly deviating molecular structures from the bulk.

  E.g.: Si_{13} (metallic-like close packing)

  Si_{45} (distorted diamond lattice)

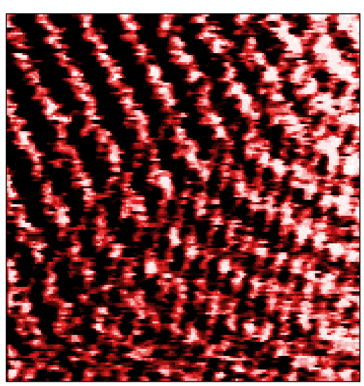
- ***Quantum Dot:***

  Small clusters: ~10^3 - 10^6 atoms (bulk-like structure) but possess discrete excited electronic states if cluster diameter less than the bulk Bohr radius, a_o, (typically < 10 nm)

$$a_o = \frac{\left(\frac{h}{2\pi}\right)^2}{m_e^{\ 2}}$$

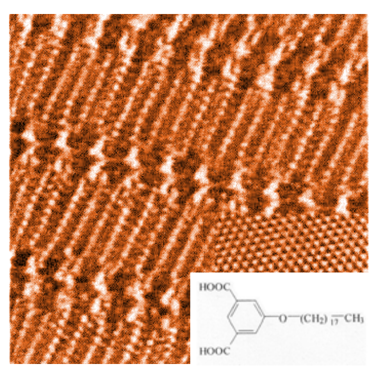
Molecular Self-Assembly

involving organic materials



Lipid Bilayer (LB Technique) on silicon oxide surface

R.M. Overney, Phys. Rev. Lett. **72**, 3546-3549 (1994)



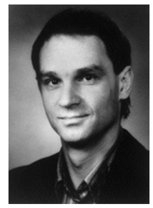
Self-assembly of C_{18}ISA on HOPG surface

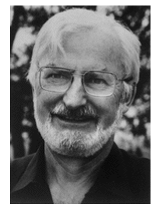
S. De Feyter et al. in Organic Mesoscopic Chemistry, Ed. H. Masuhara et al., Blackwell Science 1999

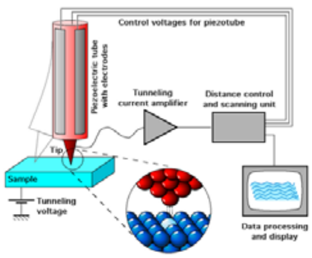
Birth of Nanoscience and Nanotechnology

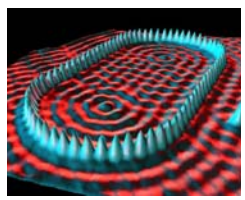
***Seeing makes believing*:** The invention of the Scanning Tunneling Microscope (STM) in Zurich (Switzerland) in 1981 marked the birth of nanoscience and nanotechnology.

Nobel Prize in Physics 1986
The prize was awarded by one half to:
ERNST RUSKA for his fundamental work in electron optics, and for the design of the first electron microscope.
GERD BINNIG and **HEINRICH ROHRER** for their design of the scanning tunneling microscope.


G. Binnig


H. Rohrer





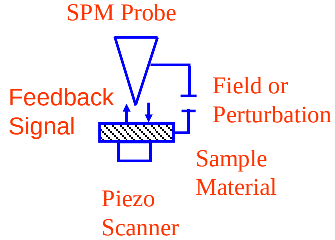
Quantum Choral Xenon Atoms on Nickel Surface (D.M. Eigler et al., IBM Almaden)

Scanning Probe Microscopy (SPM) – the Nanoscience Tool

Tools that operate in *real space* with Ångstrom to nanometer spatial resolution, in contrast to scattering techniques, such as for instance the SEM (scanning electron microscope), that operate in the *reciprocal space*.

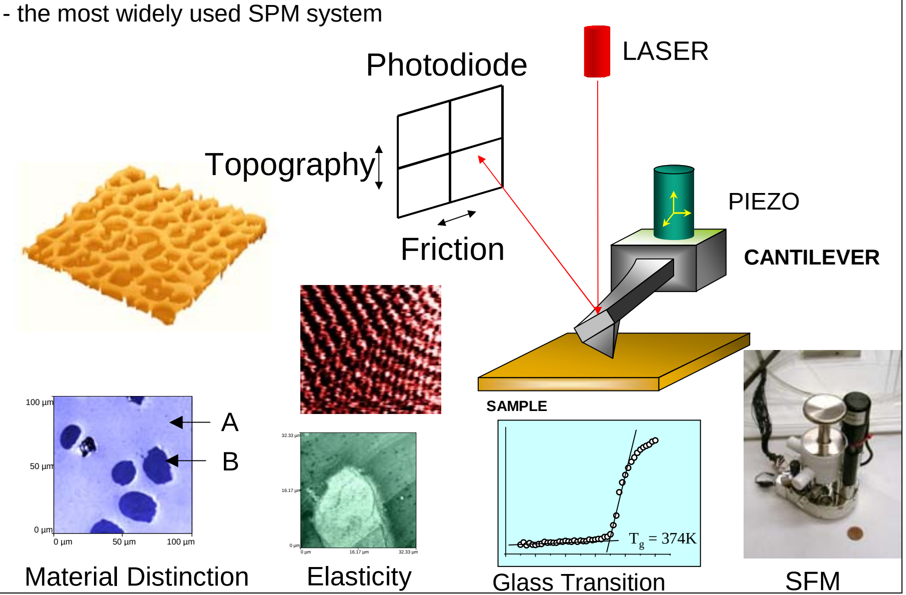
In principle, SPM systems consist of

- ***Probe Sensors*** that are *nanosized* (accomplished microlithographically),
- ***Scanning and Feedback Mechanisms*** that are accurate to the *subnanometer* level (achieved with piezoelectric material), and
- ***Highly Sophisticated Computer Controls*** (obtained with fast DACs (digital analog converters, etc.).



Scanning Force Microscopy (SFM)

- the most widely used SPM system



Nanoscience and Molecular Engineering

Molecular Sciences | Nanoscience | Surface Sciences

and *Technologies*

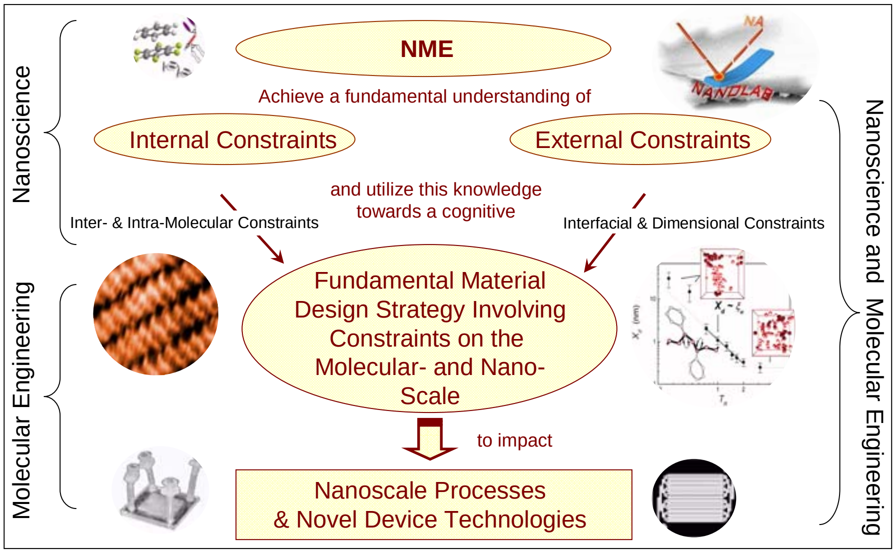
NanoScience & Molecular Engineering

- ***Cognitive engineering*** based on ***molecular designs*** and ***external constraints***.

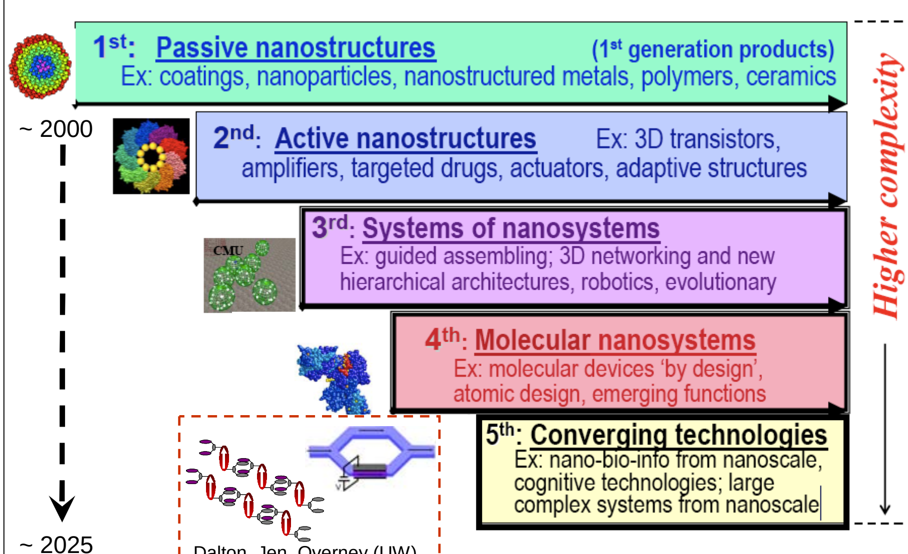
Expectations/Impact:

- Health
- Materials
- Energy
- Environment
- Consumer goods

Nanoscience and Molecular Engineering



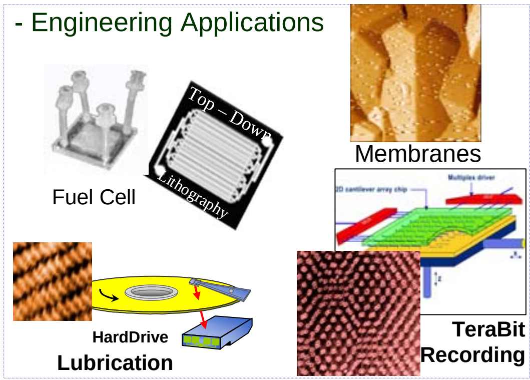
Nanoscience and Molecular Engineering



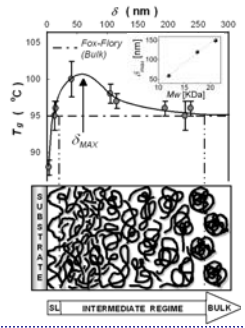
Mike Rocco (NSF), AIChE Journal, Vol. 50, 2004

Modern Technology - Engineering with Constraints

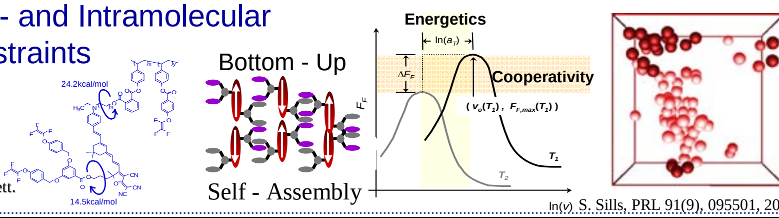
- Engineering Applications



- External Constraints



- Inter- and Intramolecular Constraints



Gray, Nano Lett. **8**, 754 (2008)

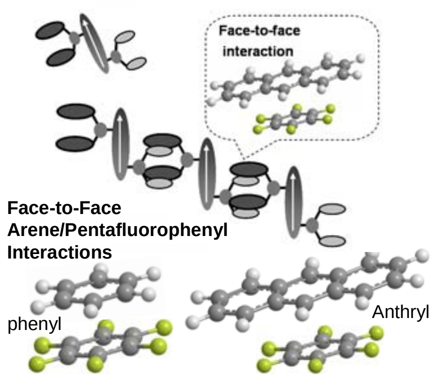
S. Sills, PRL 91(9), 095501, 2003

Inter- and Intramolecular Constraints

Example: Organic Self-Assembling Molecular Glasses

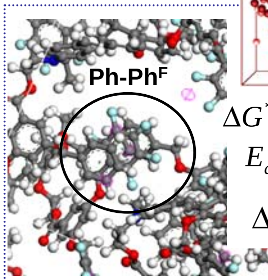
Objective: **Supramolecular interactions to create long-range molecular order**

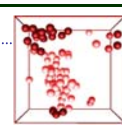
3D Quadrupolar Network



Stabilization Energy E = 4-6 kcal/mol

Stabilization Energy E = 7.3 kcal/mol



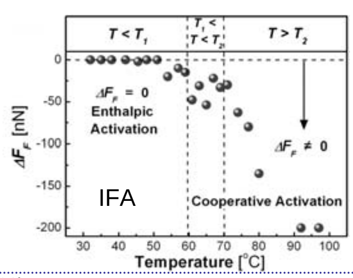


$T\Delta S*$ large

$$\Delta G^* = \Delta H^* - T\Delta S^*$$

$$E_a = E_a^o + T\Delta S^*$$

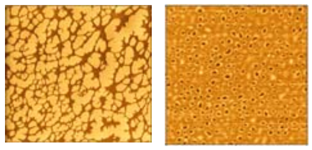
$$\Delta F_F \approx -\frac{T\Delta S*}{\phi'}$$



D. Knorr, et al., J. Phys. Chem. B, **113**, 14180-14188 (2009)

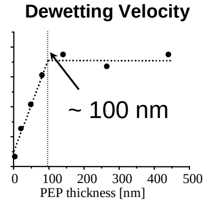
External Constraints

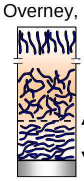
- Interfacial Constraints



Overney, J. VST B 14, (1996)

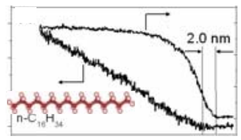
Dewetting Velocity





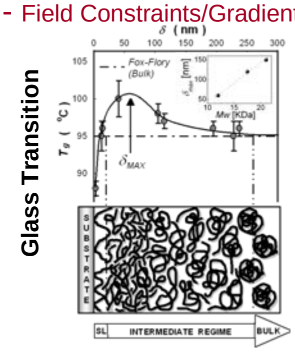
Interfacial Cooling

~ 2 nm



M. He, PRL (2000)

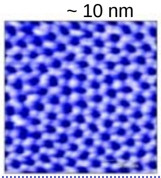
- Field Constraints/Gradients

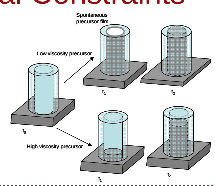


S. Sills, Chem. Phys Lett. **120**, 5334(2004)

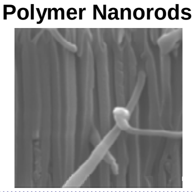
- Dimensional Constraints

~ 10 nm

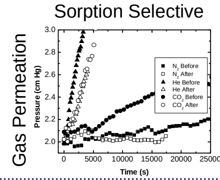




Polymer Nanorods



Size Selective → Sorption Selective



NME Research in Overney's Lab

	Intra- and Intermolecular Constraints	Interfacial and Dimensional Constraints
Fundamentals	– Side-chain and local backbone relaxations, critical energy barriers (polymers) – Molecule-molecule interaction during structuring process (molecular glasses) – Cooperativity and energy consumption, cooperative length scale – …	– Relaxations, glass transition, crystallization – Self-assembly – Glass forming process – Local mass transport properties (membranes) – …
Materials	– Condensed organic materials – Polymers (polyelectrolytes, conjugated polymers, dendritic-chromophore polymers, …) – Molecular glasses – Organic NLO materials – Proteins – …	– Ultrathin polymer films – Membranes – Nanocomposites – Organic LED materials – Simple alkane liquids – …
Impact	– Understanding phenomenological properties and processes (e.g., glass transition) – Origin of frictional energy dissipation – Cognitive approach to material engineering (e.g., towards increase in electro-optical activity in photonics) – …	– LED spectral stability – Material phase control (amorphous vs. crystalline) – Low frictional dissipation interfaces – Origin for transport properties (e.g., PEM fuel cells, reverse selective membranes) – …

R.M. Overney University of Washington

Minor in Nanoscience and Molecular Engineering (NME)

NSF 0938558

Undergraduate Minor in Nanoscience and Molecular Engineering

in departments across CoE and CoA&S

UNIVERSITY OF WASHINGTON

http://depts.washington.edu/nanolab/NUE_NME/NUE_NME.htm

Minor in Nanoscience and Molecular Engineering

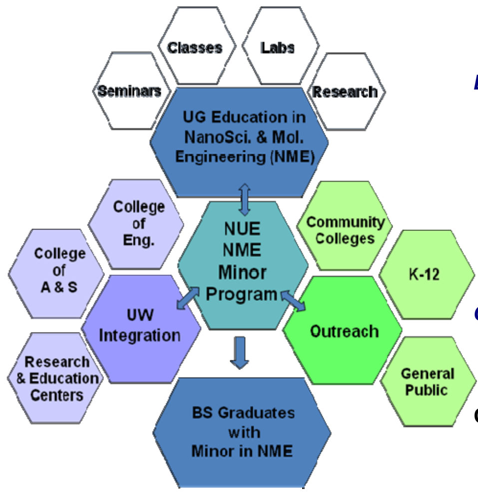
NME Mission Statement

To establish an undergraduate, discipline-tailored Minor in Nanoscience and Molecular Engineering within the University of Washington's College of Engineering (CoE) and College of Arts and Sciences (CoA&S) with integration of the wider community that empowers students for subsequent workforce or educational advancement.

10/2009 http://depts.washington.edu/nanolab/NUE_NME/NUE_NME.htm

R.M. Overney

NME Current Stakeholders



UW Stakeholders

Colleges:

- Engineering (CoE)
- Arts & Sciences (CoA&S)

Departments:

- BioEngineering (BioE)
- Chemical Engineering (ChemE)
- Chemistry (Chem)
- Electrical Engineering (EE)
- Mechanical Engineering (MechE)
- Materials Science & Engineering (MSE)
- Physics (Phys)

Centers:

- Center for Nanotechnology (CNT)
- Gen Eng Mat Sci & Eng Cntr (GEMSEC)

Community Stakeholders:

- Edmonds Community College (EdCC)
- North Seattle Community College (NSCC)

10/2009 http://depts.washington.edu/nanolab/NUE_NME/NUE_NME.htm

R.M. Overney

Minor in Nanoscience and Molecular Engineering

Example: Minor NME Curriculum in ChemE

Freshman	Sophomore	Junior	Senior
FSS-197 - Freshmen Sem. Series: NME (1) W 2010	**NME 221** Frontiers of Nanosci. and Molecular Engineering FNMI I (1) (planned for 2011)	**NME 321** FNMI II (1) (planned for 2012)	**NME 421** FNMI (III) (1) (planned for 2013)
Total credits: 21 Need at least another 4 credits; e.g., ChemE455	**ChemE 220 / NME 220** Introduction to Molecular and Nanoscale Principles (4)	**NME 320** Nanoscience and Molecular Engineering (4) Offered as ChemE 498 in Fall 2009	**NME 420** Nano-Ethics (3) (currently under development. Adapted and tailored towards NME Minor)
		NME 322 Nanosci. and Molecular Eng. Lab (3) (new LAB in MolE Building)	**NME 422** – UG Research in NME (3) (consolidated towards NME Minor)

The individual department with NME set the Minor requirement.

- Courses in ChemE (yellow)
- ChemE499 (NME approved) (green)

10/2009

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Minor in Nanoscience and Molecular Engineering

Department/Group	Representative
Founding Depts.	
ChemE	René Overney
CHEM.	Philip Reid
EE	Karl Böhringer
MSE	Mehmet Sarikaya
PHYS	Marjorie Olmstead
Additional Depts.	
AA	
BioE	Dan Ratner
Biol	
CEE	
CSE	
MechE	Jaehyun "Jae" Chung
Other Groups	
CWD	Priti Mody-Pan
CNT	Ethan Allen
CoE	
CoA&S	
Edmund CC	Mel Cossette
NSCC	Alissa Agnello

Current Departmental Representatives & Group Liaisons
(as of 10/20/09)

What else is happening on Campus?

regarding NME:

- Institute of Molecular Engineering & Science (MolE) – *established early 2010*
- Institute will also include current major Nano programs – both research and educational focus
- MolE building construction started in 2009 – *first stage finished ~ 2011/12*

Location of MolE Building

UNIVERSITY OF WASHINGTON
COLLEGE of ENGINEERING
A Community of Innovators
MOLECULAR ENGINEERING BUILDING

VIEW FROM COURTYARD | PHASE TWO