The Challenge of Water

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Water and Energy are Interdependent

Energy and power production require water (only agriculture uses more):

- Thermoelectric cooling
- Hydropower
- Fuel Production (fossil fuels, H_2, biofuels)
- Emission control
- CO_2 separation and sequestration

Dr. Michael Hightower, Sandia National Labs, 2010

Water production, processing, distribution, & end-use require energy

- Pumping
- Conveyance
- Treatment

4% of US electrical power

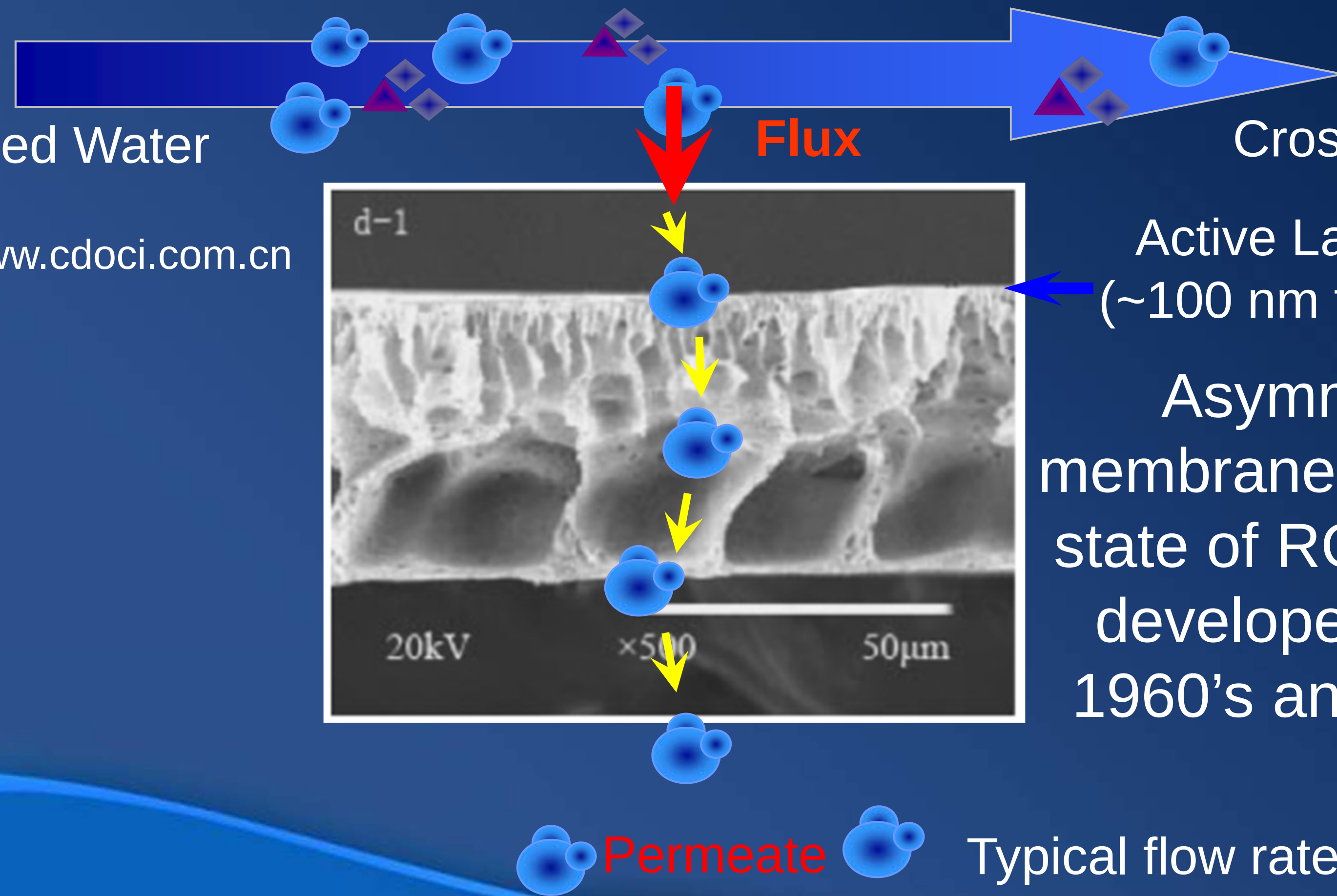
- Why are materials advances are needed in water purification?
  - Increase supplies efficiently at low cost
  - Remove micropollutants
  - Disinfect without creating dangerous byproducts
- Two examples of materials research
  - Separate with membranes
  - Sense with DNA enzymes

Using Saline Waters

- Current methods to remove salt from water (desalinate) need large amounts of capital, energy, and chemicals.
- Current methods are prone to fouling, scaling, and cost a lot to operate, needing lots of maintenance and trained workers
- Inland salt waters are full of hard salts, and disposal of brine is expensive.
- However, new methods are being developed to reduce all these problems, making certain saline source water relatively inexpensive to recover.

Desalination by Reverse Osmosis

RO has been around a long time, works well,
but much more can be done.



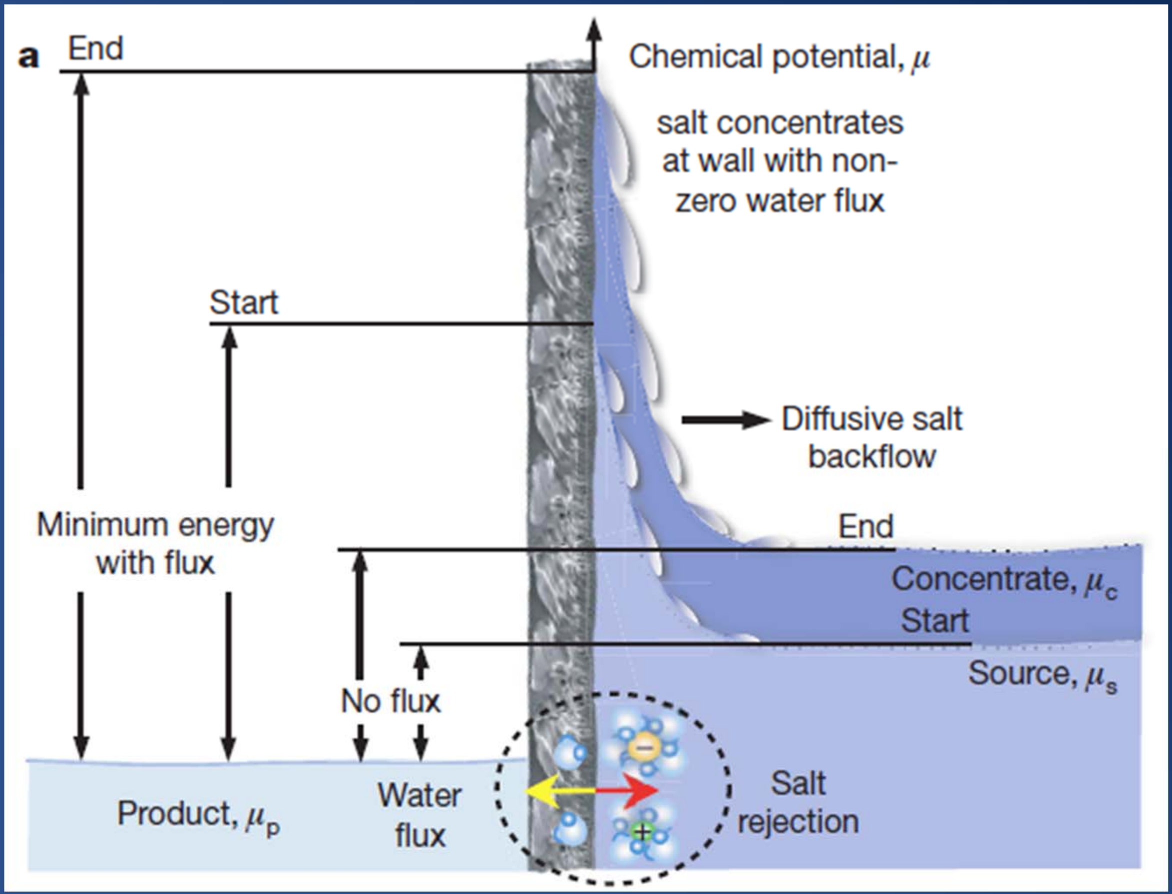
http://www.cdoci.com.cn

Active Layer
(~100 nm thick)

Asymmetric membranes: Current state of RO art, first developed in the 1960's and 1970's

Typical flow rate is 10 µm/s

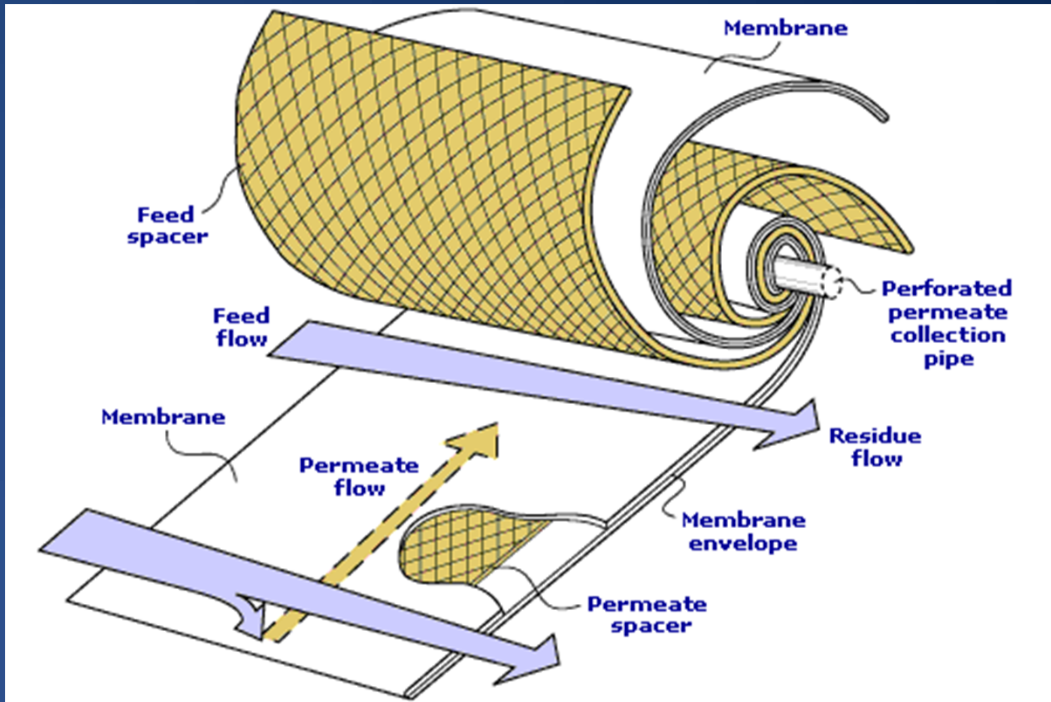
Research Needs for Reverse Osmosis



- Poor rejection of neutral, molecular contaminants
- Biological fouling
- Poor chemical stability to chlorine
- Disposal of concentrated brine

Shannon *et al.* Nature (2008)

(Concentration polarization is not to scale)



Needs lots of area:
1 million gallon/day requires one football field of membrane.

Reverse osmosis plant at Bandar Imam, Iran
www.water-technology.net

Thermodynamic limit of sea water desalination

- For 50% recovery, ideal solution, 3.5% by mass NaCl (V_0 = 2 m^3 to recover 1 m^3 pure water)

$$W = nV_0 k_B T \ln(2)$$

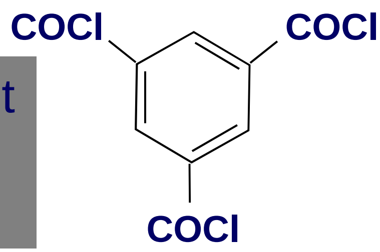
$$W = 3.8\ \mathrm{MJ} \approx 1\ \mathrm{kWh}$$

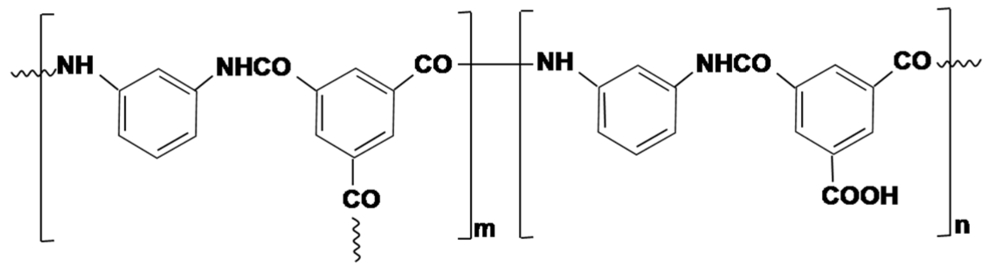
- No process can do better than this at 50% recovery. (For 0% recovery, no ln(2) term.)
- State-of-the-art RO is only a factor of 2 higher than this limit.

Almost no microscopic understanding of transport in interfacially polymerized membranes

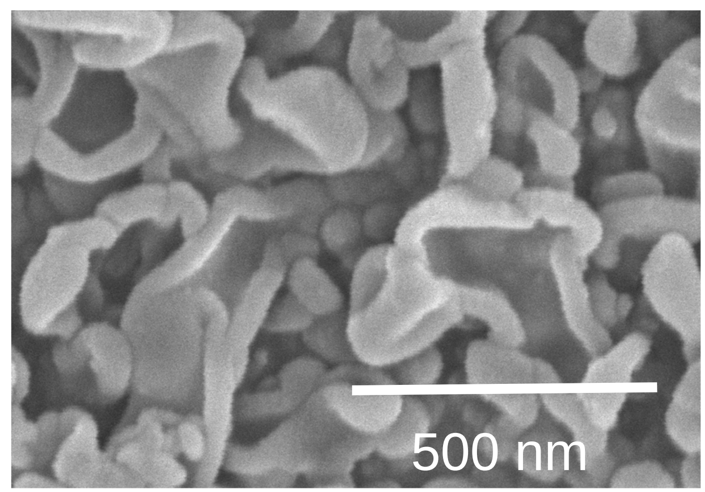
Real-world "nanotechnology": active layer is only 100 nm thick

Organic solvent + acyl halide phase

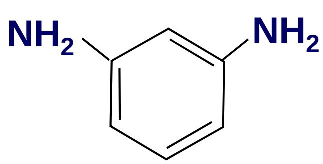




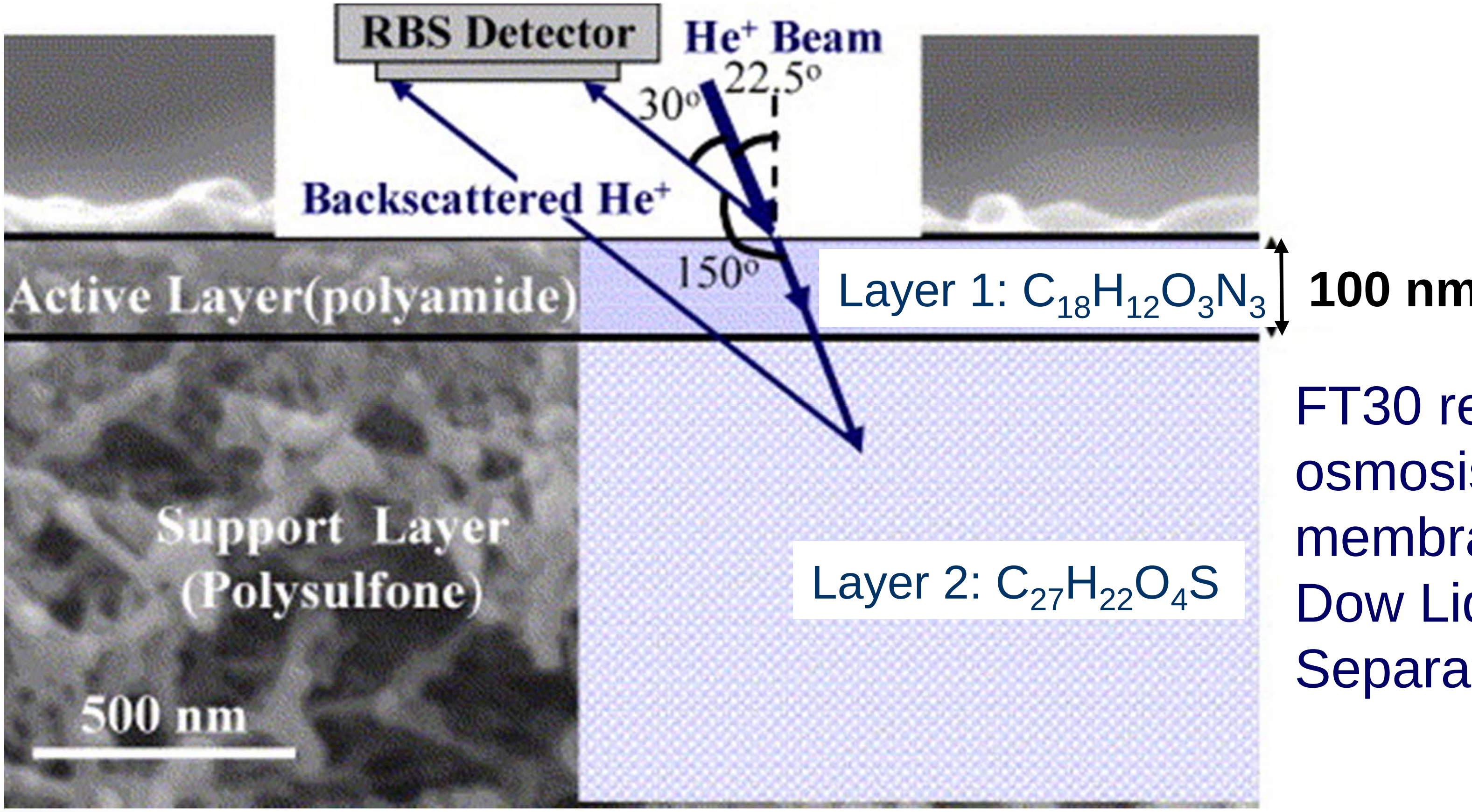
Polyamide ~100 nm



Water + amine phase

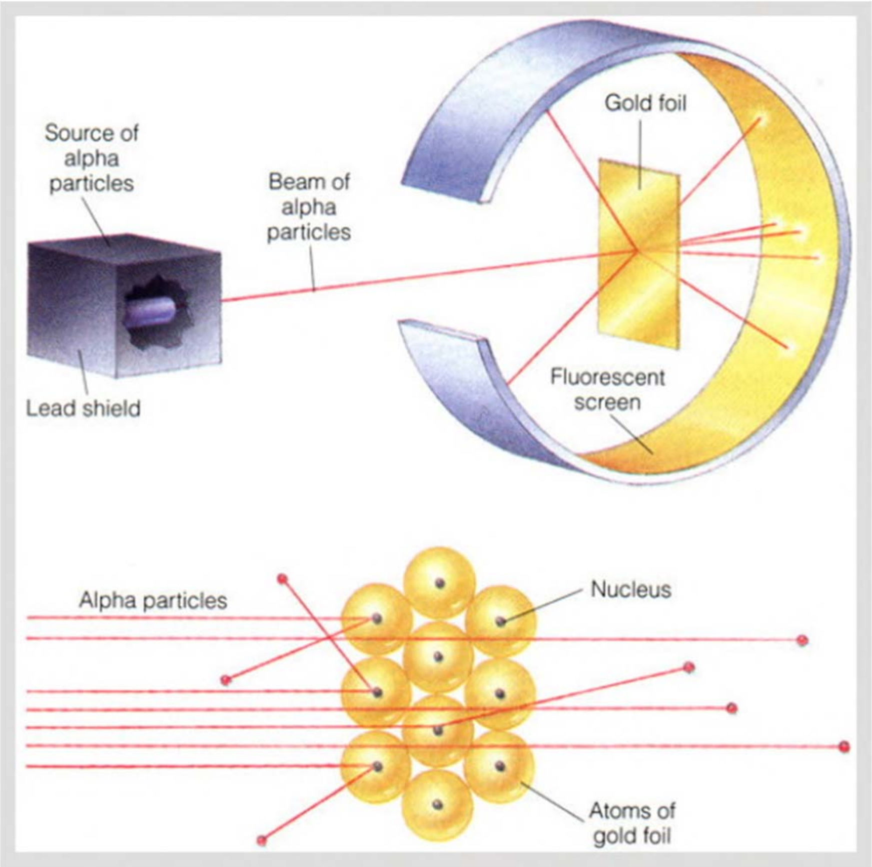


Use "Rutherford backscattering spectroscopy" as a tool for analytical chemistry on a 100 nm polymer layer



FT30 reverse osmosis membrane, Dow Liquid Separations

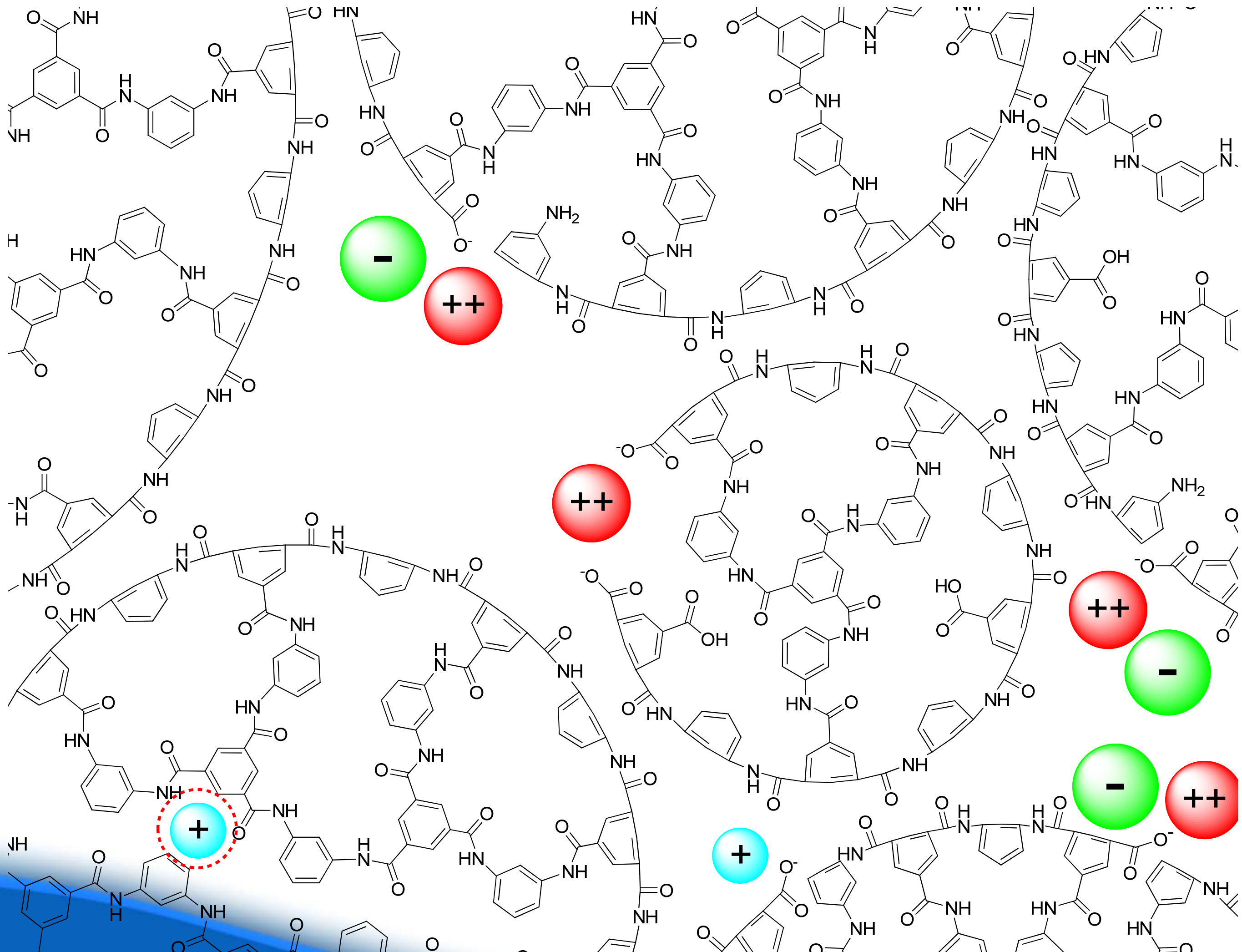
Same physics that Rutherford used to reveal the structure of the atom in 1910



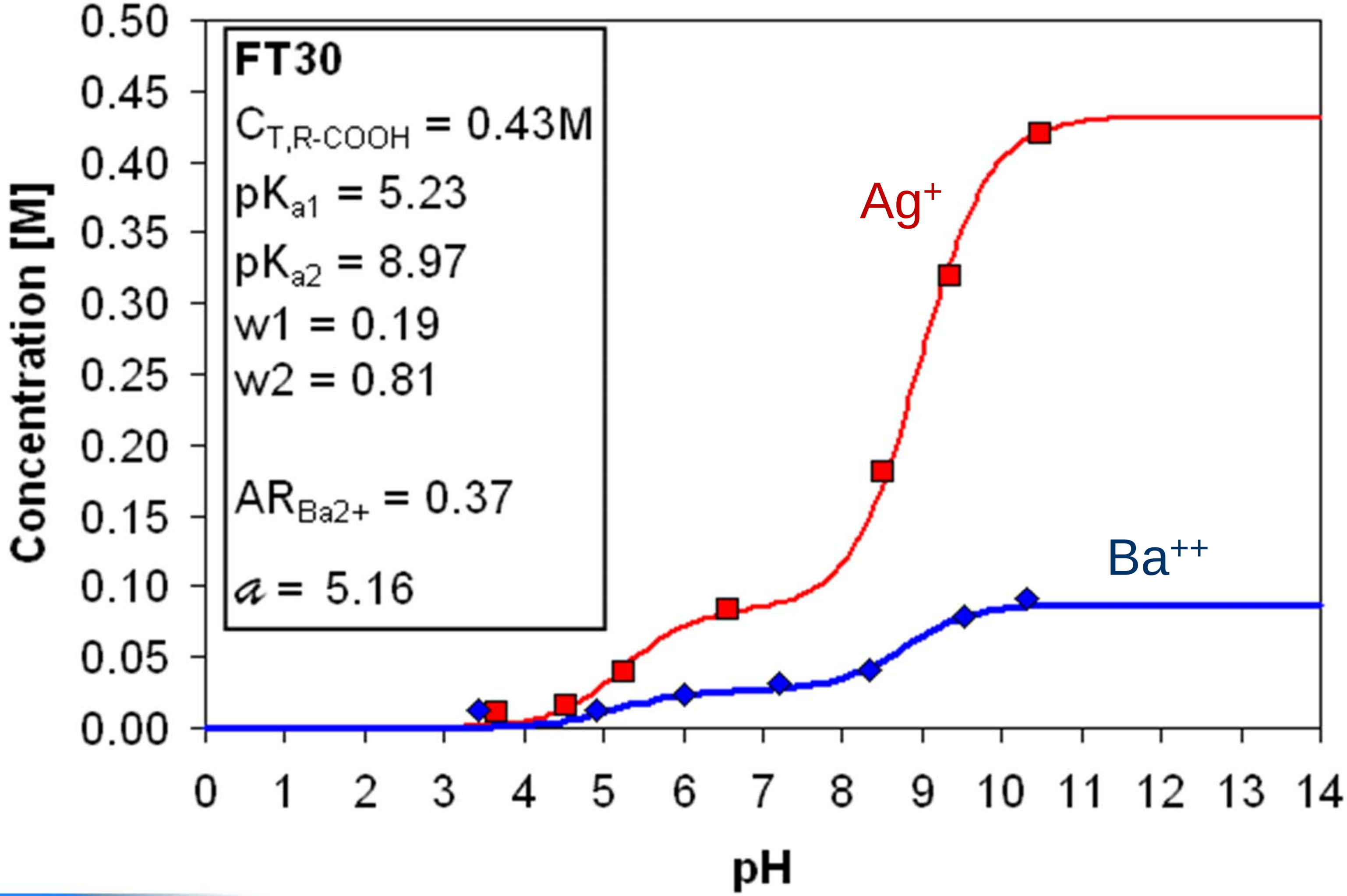
analityca.blogspot.com

2 MeV He ion accelerator at U. Illinois Materials Research Laboratory

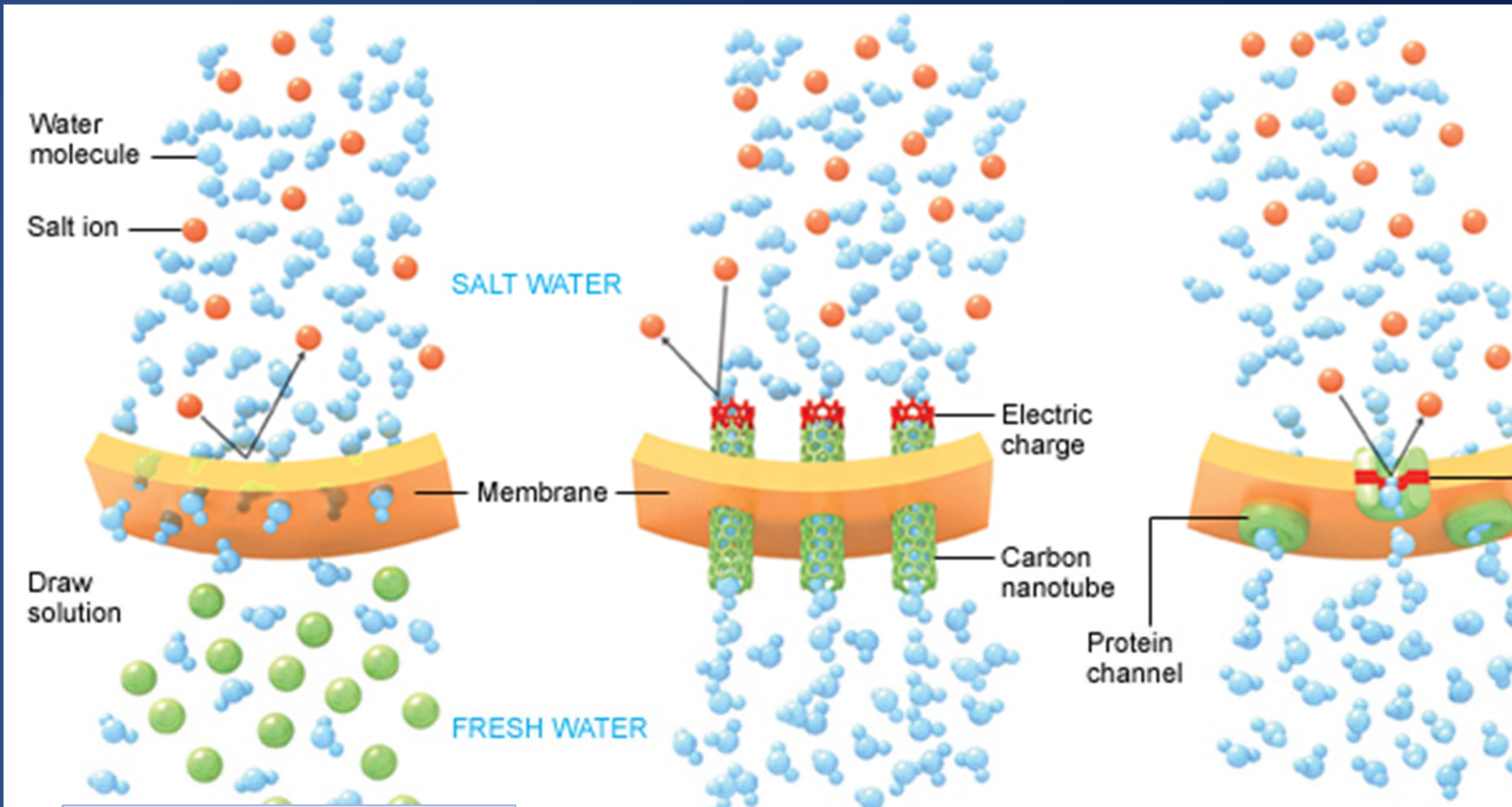
Incomplete polymerization produces charged functional groups—label $RCOO^-$ with Ba^{++} and Ag^+

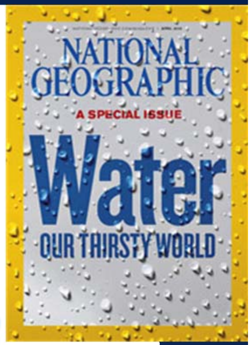


Think of this as a titration on 100 nm of membrane



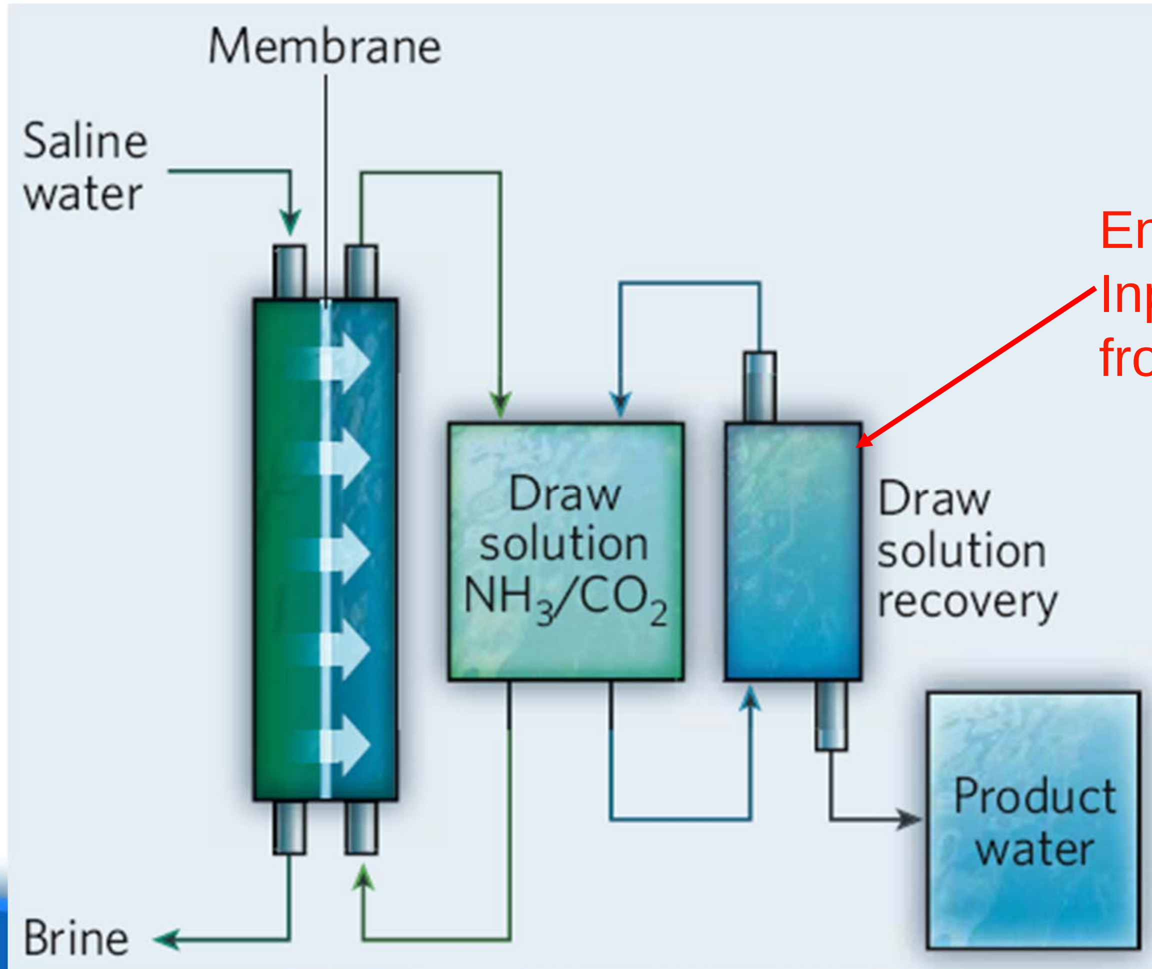
Active areas of "high-risk/high payoff" research





Forward Osmosis | **Carbon Nanotubes** | **Biomimetics**

The Ammonia-Carbon Dioxide Forward Osmosis Desalination Process

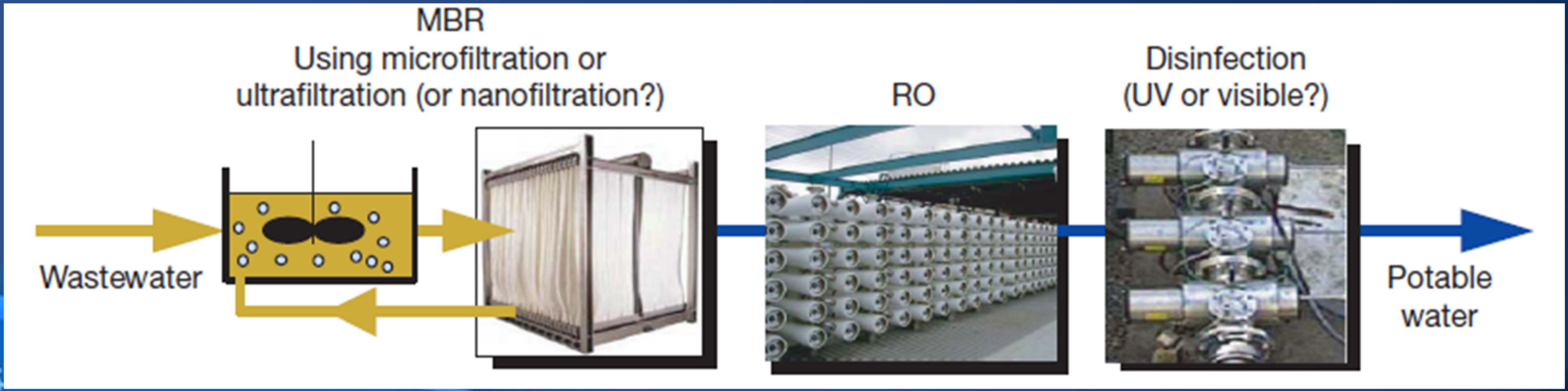


Energy
Input preferably
from waste heat

Schiermeier Nature (2008)

Advances in membrane materials could have large impact in many areas of water-energy

- Treat non-conventional sources for cooling water to reduce scaling, and remove organics that aggravate biofouling.
- Treat produced water generated by fossil fuel recovery to reduce environmental impact.
- Membranes for bioreactors (aerobic and anaerobic) that minimize biofouling.



Shannon *et al.* Nature (2008)

Savings in energy possible in treatment of source and waste waters

- U.S. ensures water safety by brute force: High pressures to prevent contamination from sewage, and high residuals of chemical disinfectants. Huge leakage.
- Downstream water quality impaired by treatment itself. Salts and disinfection byproducts
- New point-of-source, use, and discharge systems can mitigate these issues.

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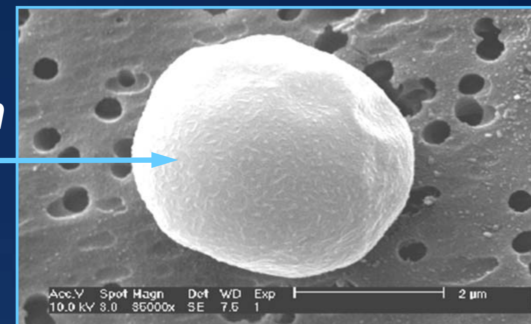
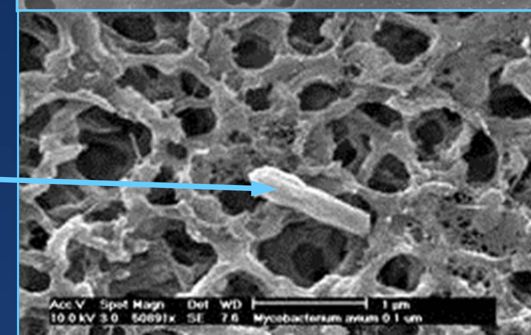
Disinfection of Hard to Treat Pathogens, Without Intensive Chemical Treatment

- Disinfect water WITHOUT using chlorine or other powerful oxidants that can themselves form toxic compounds
- Use of materials to trap pathogens, including viruses
- Use particles, catalysts, and photocatalysts with plentiful, free light to inactivate pathogens in water

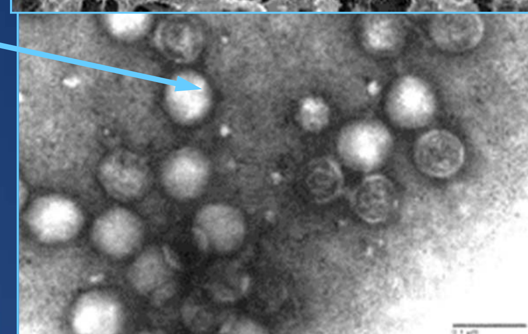
Cryptosporidium parvum

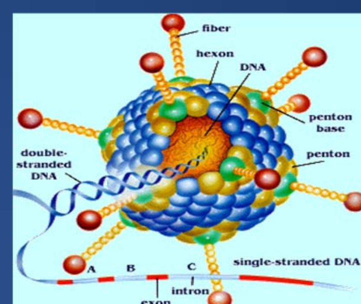


Mycobacterium avium



Adenoviruses





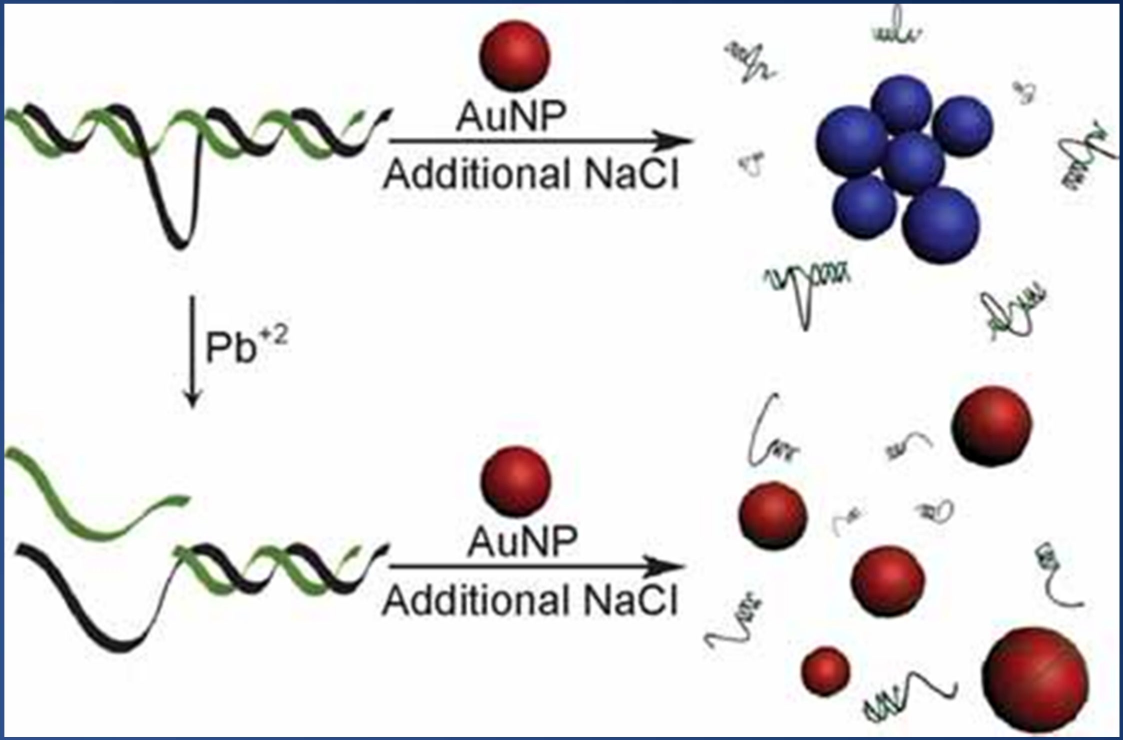
http://nobelprize.org/

Benito Mariñas, UIUC

Robust Sensing of Contaminants in Real Time Could be a Game Changer

- High cost in treating all waters all the time, when need may be much less.
- Most sensing today done in batch mode and sent to lab periodically: Difficulties in getting reliable results.
- ppb levels of toxic compounds are hard to sense in a high background of organics.
- Need to detect pathogens, including viruses.
- Fouling stops even simple sensors from working after a relatively short time.

DNAzymes for Highly Selective Heavy Sensing of Heavy Metals



http://montypython.scs.uiuc.edu

Wang *et al.,* Adv. Mat. (2008)

ANDalyze, Inc.

Real time water testing "Powered by DNA"

Some final thoughts…

- Water purification is an incredibly important problem that is underserved by the scientific community
- Many opportunities across disciplines; we need everyone's talents.
  - Materials, transport physics, engineering
  - Polymer chemistry, molecular biology
  - Microbial ecology, virology, toxicology

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