Syllabus

Description:
MatSci 192/202 will introduce students to the fundamental chemical principles underlying materials structure, properties, synthesis, and applications. Beginning from basic atomic and molecular bonding, students will learn how electronic structure impacts chemical properties and processing. Topics for the course include atomic and quantum chemistry; molecular orbital theory and molecular symmetry; solid bonding; acid-base chemistry; redox chemistry; and coordination chemistry and metal complexes. The course will also cover frontiers of materials chemistry, including nanomaterials, photocatalysis, and bioinorganic materials chemistry.

Prerequisite: Introductory chemistry and physics.
Website:  http://dionne.stanford.edu → Classes
    Also, coursework.stanford.edu

Text:  ‘Inorganic Chemistry’ (Fifth Edition), Shriver and Atkins

    I will also draw some nanomaterials content
    from ‘Materials Chemistry’ by B. Fahlman,
    available electronically using Stanford’s
    Socrates catalog.
MatSci 192/202 Policies and Dates:

1. Respect and obey Stanford’s Honor Code
   (http://www.stanford.edu/dept/vpsa/judicialaffairs/guiding/honorcode.htm)

2. Collaboration policy: Limited homework collaboration. You are welcome to discuss problems and concepts with fellow students verbally, but you should not share written work.

3. Exams will be “open note” (1 page, single sided sheet) but limited time format. Exam dates are:
   * Midterm exam (in class, 75 minute limit): Wednesday, November 2
   * Final exam: Wednesday, December 14 at 8:30am

4. Homework will generally be issued on Wednesday and will be due the following Wednesday in class. Late homework will be scored according to the relation:

   HomeworkScore(t_{days}) = HomeworkScore(Duedate)* 2^{-t} \ (integer \ t: \ 1, \ 2, \ 3,...)

Exceptions will only be granted for extenuating circumstances and with prior approval.
5. Journal Club: Each week, a team of three students will present a journal article from the recent literature highlighting applications of class topics to relevant scientific and industrial challenges. The article will be posted online the Sunday before each Wednesday presentation. Presentations should not exceed 15 minutes. Please assemble into teams of 3 using the doodle poll here: http://www.doodle.com/egtnpxidun3u7ndk

If you are not able to sign up for an oral presentation, you will be required to individually write a two-page summary, due on the day of the final, on an article of your choosing from one of the following journals: Science, Nature, Nature Materials, Nature Photonics, Nature Nanotech, JACS, PRL, APL.

6. Course grades will be weighted as follows:

   Homework: 35%
   Midterm Exam: 25%
   Final Exam: 30%
   Journal Club: 10%
A Brief History of ...materials chemistry

Today
iPhone 4, Li-ion battery

Weight: 137 g (0.3 lbs)
Battery Lifetime: 7 hr (talk time)
300 hr (standby), 2 hr recharge time
Cost: $199

1983
DynaTAC mobile phone

Lance Armstrong’s climb up Tunitas Creek (20 minutes)
Half-marathon world record (58 minutes)
Record English Channel swim (6 hours, 57 min)
If the DynaTAC battery had the capacity of the iPhone, how much would it weigh?

Today

iPhone 4, Li-ion battery

Weight: 137 g (0.3 lbs)
Battery Lifetime: 7 hr (talk time)
300 hr (standby), 2 hr recharge time
Cost: $199

1983
DynaTAC mobile phone

55' LED flat-screen TV (50 lbs)
New-born Elephant (200 lbs)
Rodin sculpture (500 lbs)
Materials chemistry & batteries

Today
iPhone 4, Li-ion battery
Weight: 137 g (0.3 lbs)
Battery Lifetime: 7 hr (talk time), 300 hr (standby), 2 hr recharge time
Cost: $199

1983
DynaTAC mobile phone
Weight: 1000 g (2.2 lbs)
Battery Lifetime: 30 min (talk time), 1 hr (standby), 10 hr recharge time
Cost: $8800 (2011 dollars)
Materials chemistry & electronic storage

2010
(32 GB)

Weight: 0.5g (0.001 lbs)
Cost: $100
Size: 11mm x 15mm x 1mm (size of a dime)

1980
(20 GB)

1 TB hard drive (~3 lbs)
Baby grand piano (~600 lbs)
Ford F-150 (~4500 lbs)
Materials chemistry & electronic storage

- **2010 (32 GB)**
  - Weight: 0.5g (0.001 lbs)
  - Cost: $100 - $150
  - Size: 11mm x 15mm x 1mm (size of a dime)

- **1980 (20 GB)**
  - Ford F-150 (~$30,000)
  - McLaren F1 (~$970,000)
  - Paul Allen’s yacht (~$100 million)
Materials chemistry & electronic storage

2010
(32 GB)

Weight: 0.5g (0.001 lbs)
Cost: $100 - $150
Size: 11mm x 15mm x 1mm (size of a dime)

1980
(20 GB)

Weight: 2,000,000 g (4400lbs)
Cost: $648,000 - $1,137,600
Size: 70” x 44” x 32” (for each 2.5 GB cabinet)
1947: the first transistor

Today: Intel quad core i7 processor (~8 billion transistors)
Not everything is going nano

20 years ago (500 calories)  Today (850 calories)

20 years ago (3 inch diameter, 140 calories) Today (5-6 inch diameter, 350 calories)
Just 15 years ago, Bob Langer and his colleague Joseph Vacanti pioneered a remarkable new process—growing human tissues in the lab. Back in 1987, Langer and Vacanti couldn’t get their work published; journal editors didn’t see any practical applications. Today, the pair are acknowledged as the fathers of the field of tissue engineering. Now, Langer, Vacanti and his brother Charles, as well as teams of researchers around the world, pursue the day when replacement tissues and organs are readily available, custom-made for those who need them. (Source: http://www.pbs.org/saf/1107/features/body.htm)

A device that recognizes tongue movements and translates them into words, serving like an artificial larynx. It fits into the mouth using a palatometer, a device typically used in speech therapy. A small synthesizer would be worn in a shirt pocket to transmit the words. (Source: http://gajitz.com/tongue-tech-artificial-larynx-tracks-tongue-transit-to-talk/)
What is materials chemistry (i.e., what will you learn)?

Probing and controlling 1) the relationships between arrangements of atoms, ions, or molecules in a material & 2) the material’s overall bulk properties

Theory
Predictions using analytic techniques (MO theory, symmetry)

Applications
energy, biomaterials, medicine, nanoscience

Synthesis
solution chemistry or bottom-up fabrication of basic building blocks

Structure
understanding extended molecular arrangements (solids and complexes)

Properties
characterizing ionic and molecular responses/reactivity to forces & fields
Egyptians: Cosmetics, Glassmaking, Metallurgy (4000 BCE)
Democritus (420 BCE): Atomic Hypothesis

“The only real things are atoms and empty space; all else is mere opinion.”
Alchemists (350BCE - 1800) – Transmutation and the Greek god Hermes
Rene-Just Hauy (1743-1822) – mineralogist who discovered crystal planes
Lavosier (1777) – discovered mass conservation, H, O; denounced phlogiston theory
Sir Humphrey Davy (1778) – inventor of electrochemistry & discoverer of alkali metals
Michael Faraday: Discovers semiconductors – negative temperature coefficient of resistance (1833)
Johann Dobereiner (1817) - noticed relations between atomic weights of similar elements

‘Dobereiner Triads’

Li = 7
Na = 7 + 16 = 23
K = 23 + 16 = 39
Ca = 12 + 8 = 20
Sr = 20 + 24 = 44
Ba = 44 + 24 = 68
S = 32
Se = 32 + 47 = 79
Te = 79 + 47 = 126

Also lateral relations were observed:
Cl - P = Br - As = I - Sb = 5
Mendeleev & Meyers (1871): ordering according to atomic weights and similar properties.

* The elements, if arranged according to their atomic weight, exhibit an apparent periodicity of properties.

* Elements which are similar in regards to their chemical properties have atomic weights which are either of nearly the same value (e.g., Pt, Ir, Os) or which increase regularly (e.g., K, Rb, Cs).

* We must expect the discovery of many yet unknown elements—for example, two elements, analogous to Al and Si, whose atomic weights would be between 65 and 75.
Luigi Galvani (1781): Precursor to the battery with “Animal Electricity.”
Alessandro Volta (1800) and John F. Daniel (1836): The first batteries. The Daniel cell produced 1.1 V and powered telegraphs and telephones for over 100 years.
William Adams and Richard Day – the first photovoltaic cell (Se, 1876)
(below: The first solar powered battery at Bell labs, 1954)
Russell Ohl – The discovery of the PN Junction (Bell Labs, 1927 – 1940)
Bardeen, Brittain, Shockley – Transistor (1948)
Linus Pauling – Explained chemical bonds using quantum mechanics

(1939)
Development and commercialization of electron microscopy (1930-1970)

1st practical TEM, 1933

From Zettl group, Science 323 (2009)

0.5 nm
Sidney Farber (1950) – Father of modern chemotherapy who helped develop anti-folates
Recent breakthroughs in materials chemistry

Organic / carbon-based devices

Catalysis

Flexible solar cells & polymeric devices

Anti-cancer drugs (Gleevec)

Metamaterials (invisibility, ultra-microscopy)

Battery technology
Upcoming materials chemistry challenges

- Highly efficient, cost effective solar cells
- Solar-fuel systems and improved battery technology
- Environmental materials engineering (e.g., water purification)
- Advanced computing (optical computing, spin computing)
- Imaging and visualization (display technology)
- Biomedical materials

“It is no good getting furious if you get stuck. What I do is keep thinking about the problem but work on something else. Sometimes it is years before I see the way forward. In the case of... black holes, it was 29 years.” - Hawking