Donald R. Sadoway
John F. Elliott Professor of Materials Chemistry
Dept. of Materials Science & Engineering (Course III)
born Toronto, Ontario, CANADA
attended University of Toronto
1972 B.A.Sc. (Engineering Science)
1973 M.A.Sc. (Chemical Metallurgy)
1977 Ph.D. (Chemical Metallurgy)
1977 NATO Postdoctoral Fellow, MIT
1978 joined MIT faculty
basic research:

*electrochemistry* in nonaqueous media

- molten salts, ionic liquids, & polymers

applied research:

- environmentally sound technologies for extraction, refining, and recycling of metals: Ti, Fe
- mobile power: solid polymer batteries;
- stationary power: colossal batteries for high amperage storage
- production of O$_2$, structural metals, and photovoltaic Si from lunar & Martian “soils”
workmanship \downarrow

\text{performance} = f(\text{design, construction}) \uparrow

\uparrow
\text{choice of materials}

\downarrow
\text{properties}

\text{composition} + \text{atomic arrangement}

\text{the thesis of 3.091:}
\text{electronic structure of the elements holds the key to understanding}

\text{syllabus}
3.091 Syllabus

1. General Principles of Chemistry

2. Solid State Chemistry:
   Basic Concepts and Applications
3.091 Introduction to Solid State Chemistry
Fall Term 2009

Lecturer  Professor Donald R. Sadoway

Subject
Administrator  Hilary Sheldon


Lectures  Monday, Wednesday, and Friday, 11:00-12:00,
Recitations  Sections meet on Tuesdays and Thursdays each week.

Homework  Weekly. Posted along with model solutions at the website. One week later, in recitation, students will take a 10-minute quiz based on the subject matter of the homework. The scores on these weekly quizzes will count as the “homework” portion of the cumulative grade in the subject. All scores count -- no dropping of lowest score(s) from the average.
3.091 Homework No. 1

- assigned today, September 9
- tested next Tuesday, September 15

celebration of learning

- posted at website along with model solutions
from Averill:

Chapter 1

<table>
<thead>
<tr>
<th>Topic</th>
<th>Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements VS Compounds</td>
<td>14, 15</td>
</tr>
<tr>
<td>Periodic Table, Reading Information of the</td>
<td>32, 36, 38, 39, 42, 44</td>
</tr>
<tr>
<td>Periodic Table, Patterns in the</td>
<td>47, 48</td>
</tr>
<tr>
<td>Isotopes</td>
<td>73, 76</td>
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<tr>
<td>Ions and Oxidation States</td>
<td>34, 82</td>
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<tr>
<td>Concept of Mole</td>
<td>25</td>
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<tr>
<td>Molecular Mass</td>
<td>65, 80</td>
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</table>

Chapter 3

<table>
<thead>
<tr>
<th>Topic</th>
<th>Problems</th>
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</thead>
<tbody>
<tr>
<td>Molecular Mass</td>
<td>33</td>
</tr>
<tr>
<td>Unit Conversions (mass to moles to molecules and vice versa)</td>
<td>35, 43, 44</td>
</tr>
<tr>
<td>Balancing Chemical Reactions</td>
<td>72</td>
</tr>
<tr>
<td>Agents in a Chemical Reaction (Limiting, in excess, etc)</td>
<td>90, 103</td>
</tr>
</tbody>
</table>
Tests

#1 Wednesday, October 7, 11:05-11:55.
#2 Wednesday, October 28, 11:05-11:55.
#3 Monday, November 23, 11:05-11:55.

permissible aids: periodic table, table of constants, calculator, and an aid sheet

FINAL EXAM:

3 hours. Time and location to be set by the Registrar and published by October 1.

Final Exam Period is December 14 – 18.

*Do not plan to leave town until after your last final.*
Grading

Freshmen -- Pass/No Record
(Institute requirement for Pass is performance at C-level or better)

Upperclassmen -- A, B, C, D, F

Final grade composition:
16.75% homework
16.75% each for three tests
33% final exam

Passing grade (C-level) ≥ 50% absolute (no grading on a curve)
Academic Honesty

It is expected that students in 3.091 will maintain the highest standards of academic honesty. In particular, it is expected that while taking a test or examination, students will not (1) accept information of any kind from others; (2) represent as their own the work of anyone else; or (3) use aids to memory other than those expressly permitted by the examiner. Following a test or examination, students will not try to deceive the teaching staff by misrepresenting or altering their previous work in order to improve their score. Please consult http://web.mit.edu/academicintegrity/.

Departures from the above standards are contrary to fundamental principles of MIT and of the scientific community at large. Such departures are considered serious offenses for which disciplinary penalties, including suspension and expulsion, can be imposed by the Institute.
Classroom Behavior

To maintain a fertile learning environment in a lecture theater seating in excess of 400 people, it is necessary for the instructor to expect adherence to certain rules of conduct. During lecture, students may not

1. hold conversations;
2. consume food or drink;
3. engage in disruptive behavior.

*Wireless communications devices must be silenced.*
3.091 Introduction to Solid-State Chemistry

Prereq: None
Units: 5-0-7
URL: http://web.mit.edu/3.091/www/

Lecture: MWF 11 (10-250) 7
Recitation Times: (Scheduled REG Day) + final

Basic principles of chemistry and their application to engineering systems. The relationship between electronic structure, chemical bonding, and atomic order. Characterization of atomic arrangements in crystalline and amorphous solids: metals, ceramics, semiconductors, and polymers (including proteins). Topical coverage of organic chemistry, solution chemistry, acid-base equilibria, electrochemistry, biochemistry, chemical kinetics, diffusion, and phase diagrams. Examples from industrial practice (including the environmental impact of chemical processes), from energy generation and storage (e.g. batteries and fuel cells), and from emerging technologies (e.g. photonic and biomedical devices).
Fall: D. R. Sadoway
Spring: D. Paul
3.091 Introduction to Solid-State Chemistry

Prereq: --
Units: 5-0-7
URL: http://web.mit.edu/3.091/www/

Lecture: MWF11 (10-250) 10 Rece
recipe for success:

venues for learning

<table>
<thead>
<tr>
<th>DRS</th>
<th>lecture</th>
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<tbody>
<tr>
<td>staff</td>
<td>recitation</td>
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<tr>
<td>you</td>
<td>reading</td>
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<tr>
<td>you</td>
<td>homework</td>
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<td>weekly quizzes</td>
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<tr>
<td>you</td>
<td>monthly tests</td>
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<tr>
<td>you</td>
<td>final exam</td>
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partnership!!!
today's lecture

taxonomy

classification

nomenclature

☞ William Shakespeare
* Chemical methods of separation include electrolysis.

† Physical methods of separation include filtration, distillation, and crystallization.

**Matter**
- Occupies space and possesses mass; may exist as solid, liquid, or gas

**Pure substance**
- Matter having an invariant chemical composition and distinct properties

**Element**
- Fundamental substance; cannot be separated into simpler substances by chemical methods

**Compound**
- Substance composed of two or more elements in fixed proportions; can be separated into simpler substances and elements only by chemical methods*

**Mixture**
- Matter consisting of two or more pure substances that retain their individual identities and can be separated by physical methods†

**Homogeneous**
- Mixture having a uniform composition and properties throughout (also called a solution)

**Heterogeneous**
- Mixture not uniform in composition and properties throughout
origins of chemistry

* ancient Egyptian hieroglyphs refer to *khemeia*: chemical processes for embalming the dead
origins of chemistry

* ancient Egyptian hieroglyphs refer to *khemeia*: chemical processes for embalming the dead

* khemeia expanded to other chemical processes, especially, metals extraction
origins of chemistry

chemistry
  gold
  silver
  copper
  iron
  tin
  lead
  mercury

astronomy
  the Sun
  the moon
  Venus
  Mars
  Jupiter
  Saturn
  Mercury
~ 2400 years ago

Image by MIT OpenCourseWare.
Aristotelean Essences
other classifications:
* “triads” 1829, Döbereiner (Jena)
other classifications:

* “triads” 1829, Döbereiner (Jena)
* “octaves” 1864, Newlands (London)

Photo courtesy of scienceheath on Flickr.
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</tr>
</thead>
<tbody>
<tr>
<td>H 1</td>
<td>F 8</td>
<td>Cl 15</td>
<td>Co &amp; Ni 22</td>
<td>Br 29</td>
<td>Pd 36</td>
<td>I 42</td>
<td>Pt &amp; Ir 50</td>
<td></td>
</tr>
<tr>
<td>Li 2</td>
<td>Na 9</td>
<td>K 16</td>
<td>Cu 23</td>
<td>Rb 30</td>
<td>Ag 37</td>
<td>Cs 44</td>
<td>Tl 51</td>
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<tr>
<td>G 3</td>
<td>Mg 10</td>
<td>Ca 17</td>
<td>Zn 25</td>
<td>Sr 31</td>
<td>Bd [sic-Cd] 38</td>
<td>Ba &amp; V 45</td>
<td>Pb 54</td>
<td></td>
</tr>
<tr>
<td>Bo 4</td>
<td>Al 11</td>
<td>Cr 19</td>
<td>Y 24</td>
<td>Ce &amp; La 33</td>
<td>U 40</td>
<td>Ta 46</td>
<td>Th 56</td>
<td></td>
</tr>
<tr>
<td>C 5</td>
<td>Si 12</td>
<td>Ti 18</td>
<td>In 26</td>
<td>Zr 32</td>
<td>Sn 39</td>
<td>W 47</td>
<td>Hg 52</td>
<td></td>
</tr>
<tr>
<td>N 6</td>
<td>P 13</td>
<td>Mn 20</td>
<td>As 27</td>
<td>Di &amp; Mo 34</td>
<td>Sb 41</td>
<td>Nb 48</td>
<td>Bi 55</td>
<td></td>
</tr>
<tr>
<td>O 7</td>
<td>S 14</td>
<td>Fe 21</td>
<td>Se 28</td>
<td>Ro &amp; Ru 35</td>
<td>Te 43</td>
<td>Au 49</td>
<td>Os 51</td>
<td></td>
</tr>
</tbody>
</table>

Note. -- Where two elements happen to have the same equivalent, both are designated by the same number.
other classifications:

* “triads” 1829, Döbereiner (Jena)
* “octaves” 1864, Newlands (London)
* “periodic table”
  1869, Mendeléef (St. Petersburg)
  1870, Meyer (Tübingen)
<table>
<thead>
<tr>
<th></th>
<th>1869</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Li</td>
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<tr>
<td>Na</td>
<td>Mg</td>
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<tr>
<td>K</td>
<td>Ca</td>
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<td>Cs</td>
<td>Ba</td>
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<tr>
<td>La</td>
<td>Ce</td>
</tr>
<tr>
<td></td>
<td>Th</td>
</tr>
</tbody>
</table>

Elements listed from top to bottom, left to right, including:
- Hydrogen (H)
- Lithium (Li)
- Beryllium (Be)
- Sodium (Na)
- Magnesium (Mg)
- Aluminum (Al)
- Silicon (Si)
- Phosphorus (P)
- Sulfur (S)
- Chlorine (Cl)
- Potassium (K)
- Calcium (Ca)
- Scandium (Sc)
- Titanium (Ti)
- Vanadium (V)
- Chromium (Cr)
- Manganese (Mn)
- Iron (Fe)
- Cobalt (Co)
- Nickel (Ni)
- Copper (Cu)
- Zinc (Zn)
- Germanium (Ge)
- Arsenic (As)
- Selenium (Se)
- Bromine (Br)
- Rubidium (Rb)
- Strontium (Sr)
- Yttrium (Y)
- Zirconium (Zr)
- Niobium (Nb)
- Tantalum (Ta)
- Ruthenium (Ru)
- Rhodium (Rh)
- Iridium (Ir)
- Platinum (Pt)
- Gold (Au)
- Mercury (Hg)
- Barium (Ba)
- Lanthanum (La)
- Cerium (Ce)
- Terbium (Tb)
- Erbium (Er)
- Thorium (Th)
- Uranium (U)

Image by MIT OpenCourseWare.
но в ней, мнѣ кажется, уже ясно выражается примѣнность выставляемаго мною начала ко всей совокупности элементовъ, пай которыхъ известны съ достовѣрностью. На этотъ разъ я и желаю преимущественно найти общую систему элементовъ. Вотъ этотъ опытъ:

\[
\begin{array}{cccccc}
\text{Ti} = 50 & \text{Zr} = 90 & \text{?} = 150 \\
\text{V} = 51 & \text{Nb} = 94 & \text{Ta} = 182 \\
\text{C} = 52 & \text{Mo} = 96 & \text{W} = 186 \\
\text{Mn} = 55 & \text{Rh} = 104,4 & \text{Pt} = 197,4 \\
\text{Fe} = 56 & \text{Ru} = 104,4 & \text{Ir} = 198 \\
\text{Ni} = \text{Co} = 59 & \text{Pl} = 106,6 & \text{Os} = 199 \\
\text{Cu} = 63,4 & \text{Ag} = 108 & \text{Hg} = 200 \\
\text{Be} = 9,4 & \text{Mg} = 24 & \text{Zn} = 65,4 & \text{Cd} = 112 \\
\text{B} = 11 & \text{Al} = 27,1 & \text{?} = 68 & \text{U} = 116 & \text{Au} = 197? \\
\text{C} = 12 & \text{Si} = 28 & \text{?} = 70 & \text{Sn} = 118 \\
\text{N} = 14 & \text{P} = 31 & \text{As} = 75 & \text{Sb} = 122 & \text{Bi} = 210 \\
\text{O} = 16 & \text{S} = 32 & \text{Se} = 79,4 & \text{Te} = 128? \\
\text{F} = 19 & \text{Cl} = 35,5 & \text{Br} = 80 & \text{I} = 127 \\
\text{Li} = 7 & \text{Na} = 23 & \text{K} = 39 & \text{Rb} = 85,4 & \text{Cs} = 133 & \text{Tl} = 204 \\
\text{Cu} = 64 & \text{Sr} = 87,6 & \text{Ba} = 137 & \text{Pb} = 207 \\
\text{?} = 45 & \text{Ce} = 92 & \text{?Er} = 56 & \text{La} = 94 \\
\text{?Y} = 60 & \text{Dy} = 95 & \text{?H} = 75,5 & \text{Th} = 118? \\
\end{array}
\]

и потому приходится въ разныхъ рядахъ иметь различное измѣненіе разностей, чего нѣть въ главныхъ числахъ представленной таблицы. Или же придется предполагать при составлении системы очень много недостающихъ членовъ. То и другое мало выгодно. Мнѣ кажется притомъ, наиболѣе естественнымъ составить кубическую систему (прелагаемая есть плоскосенная), но и попытки для ея образованія не повели къ надлежающимъ результатамъ. Ситуаций мнѣ попытки могутъ показать то разнообразие сососставленій, какое возможно при домущеніи основного начала, высказанного въ этой статьѣ.

\[
\begin{array}{cccccccc}
\text{Li} & \text{Na} & \text{K} & \text{Cu} & \text{Rb} & \text{Ag} & \text{Cs} & \text{TI} \\
7 & 23 & 39 & 63,4 & 85,4 & 108 & 133 & 204 \\
\text{Be} & \text{Mg} & \text{Ca} & \text{Zn} & \text{Sr} & \text{Cd} & \text{Ba} & \text{Pb} \\
\text{B} & \text{Al} & \text{——} & \text{——} & \text{——} & \text{——} & \text{——} & \text{——} \\
\text{C} & \text{Si} & \text{Ti} & \text{——} & \text{Zr} & \text{Sn} & \text{——} & \text{——} \\
\text{N} & \text{P} & \text{V} & \text{As} & \text{Nb} & \text{Sb} & \text{Ta} & \text{——} \\
\text{O} & \text{S} & \text{——} & \text{Se} & \text{——} & \text{Te} & \text{——} & \text{W} \\
\text{F} & \text{Cl} & \text{——} & \text{Br} & \text{——} & \text{J} & \text{——} & \text{——} \\
19 & 35,5 & 58 & 80 & 190 & 127 & 160 & 190, 220.
\end{array}
\]
<table>
<thead>
<tr>
<th>Элемент</th>
<th>Атомный номер</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li</td>
<td>7</td>
</tr>
<tr>
<td>Na</td>
<td>23</td>
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<td>K</td>
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<tr>
<td>Sr</td>
<td>37</td>
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<tr>
<td>Yb</td>
<td>60</td>
</tr>
<tr>
<td>Eu</td>
<td>75</td>
</tr>
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в потому приходится в разных рядах иметь различное изменение разностей, чего нет в главных числах предлагаемой таблицы. Или же придется предполагать при составлении системы очень много недостающих членов. То и другое мало выгодно. Мне кажется притом, наиболее естественным составить кубическую систему (предлагаемая есть плоскостная), но и попытки для ее образования не повели к надлежащим результатам. Следующие две попытки могут показать то разнообразие сопоставлений, какое возможно при допущении основного начала, высказанного в этой статье.

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<tr>
<td>Cs</td>
<td>133</td>
</tr>
<tr>
<td>Tl</td>
<td>204</td>
</tr>
</tbody>
</table>
1869

The periodic table from 1869, featuring elements labeled as eka-Boron, eka-Aluminum, eka-Silicon, and eka-Zirconium.
Д. И. Менделеев.
Портрет работы И. Е. Репина.
Д. И. Менделеев (60-е годы).