Department of Chemistry
Cumulative Examinations
January 14, 2012

You may choose to answer any exam from any area covered in the examination booklet. Each exam may contain multiple parts. You may answer more than one exam but each exam is scored separately and is treated as an individual examination result. Thus, answering parts of two exams with a score of 50% would not yield a 100% grade for this cumulative exam. Instead you would receive 50% on each examination attempted.

This booklet contains five examinations.

1) Analytical Cumulative Examination, Pages 1-2
2) Biochemistry Cumulative Examination, Page 3
3) Inorganic Cumulative Examination, Page 4
4) Organic Cumulative Examination, Pages 5-7
5) Physical Cumulative Examination, Pages 8-9

On your examination booklet:

1) Print your student ID number.
2) Print the Exam Booklet number.
3) Print the question number you are answering.
4) Print the Exam Date.

Do not write your name anywhere on the examination booklet. Each exam will be scored anonymously. If you attempt more than one exam, you must use a separate examination booklet for each examination.

When you complete the examination, return the examination and your answer booklet to the proctor. Exam results will be posted on bulletin board #2B on the north side of the hall near BRWN 2124.
Analytical Cume January 2012

NMR is a powerful technique for the analysis of complex mixtures. For example, NMR is an extremely reproducible, quantitative, versatile, high-resolution and non-destructive analytical method. However, it has several drawbacks and challenges. The following questions discuss approaches to improve the NMR analysis of complex bio-fluid samples.

1. (25 pts) High concentration species such as glucose in blood cause significant spectral overlap to occur which obscures underlying metabolite signals, and which is hard to eliminate. One possible solution is a new approach termed “Add to Subtract.” A spectrum is taken of the sample (such as blood), and then glucose or another metabolite is added to the vial before a second spectrum is acquired. By taking difference between the original and second spectrum the large peaks can be eliminated as shown below.

   ![Add to Subtract](image)

   a) Describe how the difference spectrum is computed quantitatively (you should identify the concentration of the added glucose). What happens to the overlapped and non-overlapped regions?

   b) Is there any loss or gain in signal to noise for the uncovered peaks? Compared to what? Explain your reasoning, quantitatively if possible.

   c) Would this idea work for UV-visible spectroscopy? How is it different?

   d) Could this work for mass spectrometry? Is such an approach needed? What are the challenges?

   e) This approach is somewhat related to Standard Addition method for quantitation. Describe the Standard Addition method. What differences are there?

2. (25 pts) A second challenge is quantitation. Normally, an internal standard at known concentration is added to the NMR sample in order to quantify the analytes.

   a) Explain how the concentration of an analyte is determined using this approach. What is a typical internal standard added for liquid state NMR? What property or properties of NMR is important for this to work?

   b) An alternative is to use the solvent for quantitation. How would one do this? How can one deal with the possibility that the solvent (such as water) has an enormous signal?

   c) What are benefits of using the solvent as a concentration standard? Any challenges?

   d) Does this work for other spectroscopies? Pick one and discuss how this approach could work or not work for that spectroscopy.
3. (25 pts) A third challenge is compound identification. In an NMR spectrum of a bio-fluid it is sometimes difficult to identify which peaks are from the same molecule, which if known, would help with identification.

   a) If one has multiple samples from different subjects, one can use correlation to identify peaks that are coming from the same molecule, even if the molecular concentration varies across those samples. Explain how correlation works and how it can help in this situation.

   b) An alternative is to ratio the peak intensities across the spectrum to a peak of interest (the driver peak). The peak ratios are then divided by the variation (or standard deviation) across the sample set. This approach is shown below. Write down an expression for the ratios and variances across the spectra and samples. Explain why this approach might make sense for identifying peaks from the same molecule.

   ![Diagram of NMR spectrum with driving peak and creatinine peak]

   c) What would you expect for the peak ratio to tell you about the molecule? Would those ratios change across the samples? So what would you expect the ratio variance to be? What about comparing a peak from another molecule? Would that vary across the different samples?

4. (25 pts) The last approach involves derivatization.

   a) What are some common approaches for derivatization of small molecules for use in chromatography, MS or other spectroscopies? Describe two.

   b) What are some benefits of derivatization? What are the drawbacks?

   c) Draw a derivatization reaction that might be used in one of the applications you described in a). How is the resulting derivatized molecule analyzed? How does this benefit the analysis.

   d) Imagine a complex mixture that can be derivatized. Would this help for NMR and if so how?

   e) What might you want to do to the derivatizing agent in order to make it more visible by NMR?
Cumulative Exam Questions in Biochemistry  January 14, 2012

1. Explain the following observations (10 points each):
   a. Diabetics often exhale acetone (and you can smell it on their breath) if they haven’t had their insulin shots in a while.

   b. A deficiency of folic acid leads to elevated homocysteine, reduced levels of adrenaline, and reduced DNA methylation.

   c. A deficiency in the enzyme glucose-6-phosphate dehydrogenase, which is highly prevalent around the Mediterranean, leads to a severe inability to handle foods with natural oxidants in them (e.g. fava beans, etc.).

   d. Cyanide kills almost all life forms.

2. Describe where ATP is consumed and produced a) during conversion of glucose to lactate, and b) during conversion of lactate to glucose. Then explain why the difference exists. (20 points)

3. Account for the total number of ATP molecules generated from one molecule of acetyl-SCoA by constructing a table showing: a) the name of each enzyme catalyzed reaction where energy is conserved, b) the form of metabolic intermediate (i.e. NADH, GTP, ATP, etc.) in which the energy is conserved, and c) the amount of ATP that is derived from that intermediate following oxidative phosphorylation. (40 points)
Inorganic Chemistry Cumulative Exam
Purdue University
Saturday, January 14, 2012

Question 1: (20 points)
Draw and label all the \( d \) orbitals. Put each on its own set of \( x, y, z \) axes.

Question 2: (20 points)
Draw the \( d \) orbital ligand field splitting diagram for a generic square planar complex. Label each orbital.

Question 3: (20 points)

The picture above shows a very exaggerated representation of how an octahedral complex can undergo a Jahn-Teller distortion.
A) When might such a distortion occur?
B) Explain why a compound might want to distort in this way. Figures may help your explanation. (Hint: The answer is not steric.)

Question 4: (20 points)
The complex \([\text{Fe}^{II}(\text{OH}_2)_6]^{2+}\) is attracted to a magnet and \([\text{Fe}^{II}(\text{CN})_6]^{4-}\) is not. Why? Figures may help your explanation.

Question 5: (20 points)
\( \text{Fe}^{2+} \) complexes are able to exchange ligands much more quickly than \( \text{Fe}^{3+} \) complexes. For example, the rate constants of water exchange when in aqueous solution are \( 4 \times 10^6 \text{ sec}^{-1} \) for \([\text{Fe}(\text{OH}_2)_6]^{2+}\) and \( 2 \times 10^2 \text{ sec}^{-1} \) for \([\text{Fe}(\text{OH}_2)_6]^{3+}\). Why this big difference?
Organic Chemistry Cumulative Exam - January 2012

Knowledge of named reactions is fundamental to synthetic organic chemistry. This exam will cover named reactions that begin with the letters G, H, O, and S from recent articles in J. Am. Chem. Soc. and Org. Lett.

1.) (8 points) The Stahl group reported a direct conversion of cyclohexanones to enones using palladium catalyst and oxygen. This reaction was derived from the Saegusa oxidation. Provide a mechanism from the following transformation. (J. Am. Chem. Soc. 2011, 133, 14566)

\[
\begin{array}{c}
\text{Pd(CF}_3\text{CO}_2\text{)}_2 (5 \text{ mol\%}) \\
\text{DMSO (10 mol\%)} \\
\text{AcOH, O}_2 (1 \text{ atm}), 78\% \\
\end{array}
\]

2.) (4 points) The Collins group described an investigation to control the Glaser coupling reaction at very low dilution. Draw the major product of the following reaction and clearly depict any stereochemistry. (J. Am. Chem. Soc. 2011, 133, 19976)

\[
\begin{array}{c}
\text{Et}_2\text{N, O}_2 (1 \text{ atm}), \\
\text{Et}_2\text{O, MeOH, (conc = 30 mM), 65\%}
\end{array}
\]

3.) (4 points) In their approach to magellanone, the Sarpong laboratory assembled the polycyclic core using a Hajos-Parrish reaction. Draw the product of the following reaction and clearly depict any stereochemistry. (Org. Lett. 2012, 14, ASAP)

4.) (4 points) A Stille cross-coupling was used to assemble the core of hirutellone B. Draw the product of the following reaction and clearly depict any stereochemistry. (Org. Lett. 2011, 13, 6268)

\[
\begin{array}{c}
\text{Bu}_3\text{Sn} \\
\text{Pd(PPh}_3\text{)}_4, \text{LiCl, CuCl} \\
\text{THF, 82\%}
\end{array}
\]
5.) (6 points) The Feldman group executed a Strecker reaction during their total synthesis of dragmacidin E. Draw the major product of the following reaction and clearly depict any stereochemistry. *(Org. Lett. 2011, 13, 5704)*

\[
\begin{array}{c}
\text{NH}_4\text{Cl, NH}_3, \text{MeOH} \\
\text{then TMSCN, 58%}
\end{array}
\]

6.) (8 points) An ozonolysis was used to convert a carbon-carbon double bond to an aldehyde during the synthesis of hirutellone B. Provide a mechanism for the ozonolysis of a double bond. *(Org. Lett. 2011, 13, 6268)*

\[
\begin{array}{c}
\text{OTBS} \\
\text{O}_3, \text{then PPh}_3, \text{CH}_2\text{Cl}_2, 98%
\end{array}
\]

7.) (4 points) An unexpected Grob fragmentation was observed with a secondary alcohol during the preparation of azaspiro[3.3]heptanes by the Carreira group. Draw the product from this fragmentation and clearly depict any stereochemistry. *(Org. Lett. 2012, 14, ASAP)*

\[
\begin{array}{c}
\text{KOH-Bu, THF, 53%}
\end{array}
\]

8.) (4 points) A Horner-Wadsworth-Emmons reaction was used during the total synthesis of bistramide A by the Cossy laboratory. Draw the product of the following reaction and clearly depict any stereochemistry. *(Org. Lett. 2011, 13, 6018)*

\[
\begin{array}{c}
\text{CHO} \\
\text{NHPhth}
\end{array}
\]

\[
\begin{array}{c}
\text{O} \\
\text{P(\text{OEt})}_2
\end{array}
\]

\[
\begin{array}{c}
\text{Ba(OH)}_2\text{-8H}_2\text{O, THF, 75%}
\end{array}
\]
9.) (4 points) Tetrahydroisoquinolines were converted to iminium ions using photoredox catalysis and subsequently subjected to a Henry reaction. Draw the product of this reaction using the iminium ion intermediate shown below. (Org. Lett. 2012, 14, ASAP)

10.) (8 points) In the total synthesis of the marine toxin, (-)-gymnodimine, the Romo group executed a Swern oxidation on a primary alcohol to give an aldehyde in 99% yield. Provide a mechanism for this oxidation. (J. Am. Chem. Soc. 2011, 133, 19844)

11.) (6 points) A Heck reaction was used in the total synthesis of minfiensine. Draw the product from this reaction and clearly depict any stereochemistry. (Org. Lett. 2011, 13, 6426)
PHYSICAL CHEMISTRY

The questions are adapted from Journal of Chemical Education 84, 1840, 2007. Please turn in this question sheet together with your blue book as you will need to fill out part of your answers in question 1 and question 4 here.

Name:

The one dimensional Particle-in-a-Box (PB) model is often used to model the transition of π electrons in conjugated chain molecules. The PB energy levels for a particle in a ‘box’ of length \( L \) are \( E_n = \frac{n^2 \hbar^2}{8mL^2} \), \( n = 1, 2, 3.. \) where \( n \) is quantum number, \( m \) is the particle mass (mass of electron: \( m_e = 9.11 \times 10^{-31} \) kg) and \( \hbar \) is Planck’s constant (\( \hbar = 6.626 \times 10^{-24} \) J s).

One can easily calculate the longest absorption wavelength, \( \lambda \), of conjugated chain molecules. \( \lambda \) is corresponding to the energy gap between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO). The only adjustable parameter is the box length, \( L \).

1. (50 pts) Consider cyanine dyes as follows

\[
\text{H} - \text{C} = \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{N}^+ \quad \text{H} - \text{C} = \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{N}^+ \quad \text{H}
\]

with \( k = 0, 1, 2, 3, ... \). Assume \( L = [249(k+1)+567] \) pm (i.e. \( 10^{-12} \) m).

Find the quantum number \( n_{\text{HOMO}} \) corresponds to HOMO level and calculate \( \lambda \) (in unit of nm) for cyanines for \( k = 0, 1, 2, 3, \)

<table>
<thead>
<tr>
<th>( k )</th>
<th>( n_{\text{HOMO}} )</th>
<th>Calculated ( \lambda ) (nm)</th>
<th>Experimental ( \lambda ) (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td>313</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>416</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>519</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>625</td>
<td></td>
</tr>
</tbody>
</table>

2. One of the approximations made when the PB model is applicable to treat cyanines is that the potential \( V(x) \) is assumed to be constant over the length of the box. However, in reality there are variations of the potential. Such variation in the potential should reflect the position of the atoms in the molecule. Let the perturbing potential of the PB potential be \( V'(x) \). Consider \( V'(x) = A \cos(\frac{2m\pi}{L}x) \) where \( m = 2k + 5 \), \( m \) is the total number of atoms in the chain backbone. The factor \( A \) represents the strength of the perturbation. See the figure of \( V'(x) \) in the next page.

(10 pts) Provide a rationale on why \( V'(x) = A \cos(\frac{2m\pi}{L}x) \) is a reasonable approximate of the potential variation.

(10 pts) Write down \( E'_n \), the first-order correction to the energy of each level \( E_n \)
3. (20 pts) PB model can also be applied to polyenes. Two examples of polyenes are shown below.

![Diagram of polyenes with absorption wavelengths]

Figure 3. Longest absorption wavelength of polyenes as a function of chain length. Ph = phenyl. Experimental wavelengths $\lambda_{\text{max}}$ taken from ref 17, Table 2.2. The lines are fits according to a modified PB model that accounts for bond-length alternation, see Table 2.

Explain why $\lambda$ increases with respect to the increase of $k$. Use some calculation to support your explanation if necessary.

4. (10 pts) Polyenes have a significant bond-length alternation because the bonds cannot be represented as both single and double bonds in equivalent resonance structures as the cyanines. Propose a perturbing potential $V'(x)$ function to present such bond-length alternation by sketching a $V'(x)$ for a polyene with $k=1$. 

![Sketch of V'(x) for polyene]
# Periodic Classification of the Elements

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>He</td>
<td>Li</td>
<td>Be</td>
<td>B</td>
<td>C</td>
<td>N</td>
<td>O</td>
<td>F</td>
<td>Ne</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>19</td>
<td>20</td>
</tr>
<tr>
<td>Na</td>
<td>Mg</td>
<td>Al</td>
<td>Si</td>
<td>P</td>
<td>S</td>
<td>Cl</td>
<td>Ar</td>
<td>K</td>
<td>Ca</td>
</tr>
<tr>
<td>37</td>
<td>38</td>
<td>39</td>
<td>40</td>
<td>41</td>
<td>42</td>
<td>43</td>
<td>44</td>
<td>45</td>
<td>46</td>
</tr>
<tr>
<td>Rb</td>
<td>Sr</td>
<td>Y</td>
<td>Zr</td>
<td>Nb</td>
<td>Mo</td>
<td>Tc</td>
<td>Ru</td>
<td>Rh</td>
<td>Pd</td>
</tr>
<tr>
<td>85.47</td>
<td>87.62</td>
<td>88.905</td>
<td>91.22</td>
<td>92.906</td>
<td>95.94</td>
<td>99</td>
<td>101.07</td>
<td>102.903</td>
<td>106.4</td>
</tr>
<tr>
<td>55</td>
<td>56</td>
<td>57</td>
<td>58</td>
<td>59</td>
<td>60</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>64</td>
</tr>
<tr>
<td>Cs</td>
<td>Ba</td>
<td>La*</td>
<td>Hf</td>
<td>Ta</td>
<td>W</td>
<td>Re</td>
<td>Os</td>
<td>Ir</td>
<td>Pt</td>
</tr>
<tr>
<td>132.905</td>
<td>137.34</td>
<td>138.91</td>
<td>178.49</td>
<td>180.948</td>
<td>183.85</td>
<td>186.2</td>
<td>190.2</td>
<td>192.2</td>
<td>195.09</td>
</tr>
<tr>
<td>87</td>
<td>88</td>
<td>89</td>
<td>90</td>
<td>91</td>
<td>92</td>
<td>93</td>
<td>94</td>
<td>95</td>
<td>96</td>
</tr>
<tr>
<td>Fr</td>
<td>Ra</td>
<td>Ac†</td>
<td>Th</td>
<td>Pa</td>
<td>U</td>
<td>Np</td>
<td>Pu</td>
<td>Am</td>
<td>Cm</td>
</tr>
<tr>
<td>223</td>
<td>226</td>
<td>227</td>
<td>232.038</td>
<td>238.03</td>
<td>237</td>
<td>242</td>
<td>243</td>
<td>247</td>
<td>249</td>
</tr>
</tbody>
</table>

*Lanthanides*<br>58 Ce 140.12 140.907<br>60 Nd 144.24 147<br>62 Sm 150.35 151.96<br>63 Eu 157.25<br>64 Gd 158.924<br>65 Tb 162.50<br>66 Dy 164.930<br>67 Ho 167.26<br>68 Er 168.934<br>69 Tm 173.04<br>70 Yb 174.97<br>71 Lu

†Actinides<br>90 Th 232.038<br>91 Pa 238.03<br>92 U 237<br>93 Np 242<br>94 Pu 243<br>95 Am 247<br>96 Cm 249<br>97 Bk 254<br>98 Cf 253<br>99 Es 256<br>100 Fm 256<br>101 Md (256)<br>102 No (257)<br>103 Lw (257)

(Numbers in parentheses are the mass numbers of the most stable isotopes.)