**Chem 51A Final Review Key**

### Section I: Multiple Choice (15 Questions)

1. Rank the conjugate bases below based on increasing basicity.

   ![Conjugate Bases](image)

   a. III > II > I  
   b. II > I > III  
   c. III > I > II  
   d. I > II > III

   Pay attention to the wording of the question. Increasing basicity means least to most basic. I originally said B is the correct answer because least basic to most basic is II, I, III. However, the arrows " > " were misleading. So since all the answers are using " > " greater than, C is the true answer.

2. In the energy coordinate diagram below, which of the following is represented by A?

   ![Energy Coordinate Diagram](image)

   a. [R—Nuc:—X]  
   b. [R---X]  
   c. [R—Nuc:]
d. \([R---\text{Nuc}---X]\)

Don’t forget the double dagger and partial charges! I wasn’t able to put that in this document but make sure to draw on test!

3. Which of the following Lewis structures represent the Newman Projection below? (Ans: D)

![Newman Projection Image]

Count the number of carbons linked together in the middle of the Newman projection. There is 5, and since they are connected, it is a 5 carbon ring. Up in the newman projection = solid wedge. Down is dash wedge.

4. The two compounds shown below are:

![Compounds Image]

a. Identical
b. Enantiomers
c. Diastereomers
d. Constitutional isomers
e. Different but not isomeric

5. Which of the following molecules is achiral?
a. (2R,3R)-2,3-Dichloropentane  
b. (2R,3S)-2,3-Dichloropentane  
c. (2S,4S)-2,4-Dichloropentane  
d. (2S,4R)-2,4-Dichloropentane  
e. Two of these

6. What is the percent composition of a mixture of (S)-(+)-2-butanol, [α]=+13.52° and (R)-(-)-2-butanol, [α] = -13.52°, with a specific rotation [α]= +6.76°?
   a. 75%(R) 25%(S)  
b. 25%(R) 75%(S)  
c. 50%(R) 50%(S)  
d. 67%(R) 33%(S)

7. What is the parent chain for the compound shown below?

   a. Hexane  
b. Heptane  
c. Octane  
d. Nonane

8. Which of the following compounds has the lowest boiling point?

   A  
   B  
   C  
   D

   a. A  
b. B  
c. C → VDW only, most branching  
d. D
9. During the synthesis of DNA, nucleotides are joined together through the formation of phosphodiester bonds (shown below). What type of reaction is this?

![Phosphodiester Bond](image)

a. Addition reaction - One pi bond is broken to form two sigma bond
b. Substitution reaction - One sigma bond is broken to form a sigma bond
c. Elimination reaction - Two sigma bonds are broken to form a pi bond (double bond)
d. Radical reaction - When two molecules with one electron each interact with each other

10. Consider the reaction below. Which step is the rate determining step?
11. Which of the following statements regarding the stereoisomers are true?

I. Stereoisomers A and B are diastereomers True  
II. Stereoisomers A and C are enantiomers A and C are diastereomers  
III. Stereoisomers A and D are meso compounds True, Achiral with stereocenters

a. I only  
b. I and II  
c. II and III  
d. I and III  
e. I, II, and III

12. Which of the following skeletal structures depicts the following cyclohexane ring conformation? (Et signifies -CH₃CH₃) ANSWER: C
13. Consider the following reaction:

\[
\cdot\text{CH}_3 + \cdot\text{Cl}^- \rightarrow \text{CH}_3\text{Cl}^-
\]

Which of the following statements regarding the chemical reaction below is TRUE?

a. Reaction can be characterized as a substitution reaction
b. \(\Delta H^\circ\) of the reaction is positive

c. \(\Delta S^\circ\) of the reaction is negative \(\text{more ordered} = \text{decrease in entropy}\)
d. The reverse reaction (products to reactants) is considered heterolytic cleavage

e. Bond dissociation energy of the C-Cl bond in the products is positive

14. Which of the following statements regarding IR Spectroscopy is FALSE?

a. Wavenumber is inverse wavelength (cm\(^{-1}\))

b. Bond between heavier atoms will oscillate more frequently \(\text{(see chapter 13 text)}\)

c. Higher energy bonds will oscillate more frequently

d. Bonds with greater electronegativity differences will oscillate more frequently

e. All Statements are true

15. Which of the following statements regarding NMR Spectroscopy is TRUE?

a. The splitting in \(^1\text{H}\) NMR is caused by the number of Hydrogens in an individual chemical environment \(\text{Definition of integration}\)

b. The integration values in \(^1\text{H}\) NMR is caused by the number of Hydrogens in adjacent chemical environments \(\text{Definition of splitting}\)

c. Deshielding effects cause \(^1\text{H}\) NMR signals to shift more upfield, Deshielding causes peaks to be more downfield

d. Carbonyl Carbons are more upfield than sp\(^3\) hybridized Carbons in \(^{13}\text{C}\) NMR,\(\text{Oxygen in carbonyl pulls e- density away from carbon, carbon is more deshielded and more downfield}\)
All of the above are false, sorry for confusion

**Section II: Short Answer (4 Questions)**

1. Part 1: Use the arrangement below to draw a correct Lewis structure with all lone pairs and non-zero formal charges included

   Part 2: Draw all possible resonance structures based on the compound. Include all lone pairs and formal charges.

2. Huntington’s disease is a hereditary disease that causes the progressive death of nerve cells. Tetrabenazine is a drug that treats involuntary body movements caused by Huntington’s disease. Below is the molecular structure for one stereoisomer of Tetrabenazine.
Tetrabenazine

a. Assign R or S to all stereoisomers.

b. Draw a diastereomer for the isomer of Tetrabenazine shown above.

c. On the Tetrabenazine below, draw how water molecules (H2O) will bond to the molecule for each hydrogen-bonding site.
d. Can Tetrabenazine act as a hydrogen-bond donor? Explain why or why not.

No, Tetrabenazine cannot act as a hydrogen-bond donor because the atoms that can participate in hydrogen bonding in Tetrabenazine do not have a hydrogen atom attached. Therefore, they can only participate as hydrogen-bond acceptors.

3. Lidocaine is a local anesthetic agent used to treat a variety of cases involving pain or itchiness such as sunburn, poison ivy exposure, or minor cuts. Below is the IR and NMR spectras of lidocaine. The chemical structure of lidocaine has also been provided.

IR spectrum:
H NMR:

a. Determine which function groups are present within the spectrum along with its corresponding wavenumber.

At ~1700 cm$^{-1}$, there is an amide/ketone functional group present
At ~3000 cm$^{-1}$, there are sp3 C-H bonds present
At ~3100 cm$^{-1}$, there are sp2 C-H bonds present
At ~3300 cm$^{-1}$, there is an amide functional group present

Since you’re provided with the chemical structure beforehand, try to find the functional groups within lidocaine so you have a better idea of what functional groups you should expect on the IR spectras. At 1600-1700 cm$^{-1}$ we typically find ketones. At 3400-3500 cm$^{-1}$ we confirm that our ketone is more specifically an amide. The signal can’t be an alcohol because we don’t see an alcohol. If you don’t see the functional group in the structure, that signal is probably
something else. At 2900-3000 cm\(^{-1}\) we will always expect to see an sp\(^3\) C-H bond. Sp\(^3\) C-H bonds means that we have a carbon bonded to a hydrogen and three other substituents. Four bonds indicates that this carbon is sp\(^3\) hybridized. At 3000 cm\(^{-1}\) we expect to see an sp\(^2\) C-H bond. What this represents is the double bonds (in the benzene ring) since the double bonded carbons are sp\(^2\) hybridized.

b. Assign each peak to a set of protons based on the information from the \(^1\)H NMR spectra. For how many protons should each peak integrate for?

- Ha: \(\sim 7.2\) ppm, 3H
- Hb: 2.3 ppm, 3H
- Hc: 9.0 ppm, 1H
- Hd: 3.6 ppm, 2H
- He: \(\sim 3.0\) ppm, 2H
- Hf: \(\sim 1.2\) ppm, 3H

Recall that the higher our chemical shift (more towards the left), the more deshielded the protons are. This is because close towards electron withdrawing groups (EWG) (ie. oxygen, nitrogen - both electronegative and therefore electron withdrawing). Towards the right, the protons are more deshielded because they will be farther away from EWG/ on carbons not next to EWGs. To solve NMR spectras, solve which peaks refer to which protons from left to right because the left signals can give you a better clue on where the protons are. The right side is more difficult because it’s usually all alkanes bonded to each other. At 9.0 ppm we have a singlet peak. At 9-10 ppm we will always see signals for carbonyl groups (amide, carboxylic acid, aldehyde). This is confirmed by the singlet pattern because a singlet tells us that it will have no neighbors. Recall that the N+1 rule refers to how many adjacent protons we have \(+ 1\) = the signal. Since we have a singlet \(0 + 1 = 1\).

At 7.2 ppm, we will expect to see a proton signal for the benzene rings. It’s not any other signal because only the only signals here correlate to benzene. Even though benzene has three protons, there is a singlet splitting pattern because it the adjacent carbons next to these protons do not have protons themselves. There are methyl groups if you go one carbon further but because the adjacent carbon next to the carbon containing our protons does not have protons, it would not expect to see a splitting pattern (tldr: It’s a singlet because the protons closest to it are too far away to cause splitting).

At 3.6 ppm we will expect to see the proton signal for the proton signal between the carbonyl and nitrogen atom. We know that it’s the set of protons in between the carbonyl and nitrogen because 1) signals at 2.5-4.0 ppm represent the proton signal on the carbon next to N, O, or a
halogen (see the NMR chart that will be provided on the exam). Additionally, it’s a singlet peak so the protons will not have any neighbors. Also, the set of protons in between the nitrogen and carbonyl cannot be the signal at 2.3 ppm because the set of protons I mentioned is somewhat near some deshielding groups (nitrogen and oxygen on carbonyl), therefore it must be the singlet peak that’s further downfield.

Based on a process of elimination, our last singlet peak at 2.3 ppm must be the two methyl groups. Notice the carbons next to the methyl groups. Carbons aren’t very electronegative so that’s one reason why the signal for the methyl group is so far to the right. Also notice how the two methyl groups have the same signal. All of the hydrogens are equivalent. If you draw a line in between the benzene ring you will see that there is a line of symmetry. If you see a line of symmetry, you would expect to see equivalent protons and therefore one signal for a whole group of protons.

Lastly, we have our quartet at 3.0 ppm and triplet at 1.2 ppm. Based on the N + 1 rule, we see that our protons of interest is next to three other protons. Therefore, it would mean that those neighbors are the methyl group protons. Thus, the quarter signal belongs to the He protons. The signal at 1.2 ppm is the methyl groups at the end. We know that it’s the methyl groups at the end (Hf) because the chemical shift is so low indicating that our methyl groups are not near any deshielding groups.

c. Is the carbon on the amide electrophilic or nucleophilic? Use resonance structures to show why.

Electrophilic. This is because for one possible structures involving carbonyls, the oxygen will move the electrons towards itself leaving an oxygen ion and a carbocation. Carbocations are unstable because they do not have a full octet. Therefore, it will want electrons (ie. by forming another bond with another atom) in order to fulfill its octet. Therefore, it’s an electrophile because it wants electrons.
d. Compare the position of the proton’s NMR peak in the amide on lidocaine with the amino group. Explain why the peak for one functional group is further downfield than the other.

The position of the amide’s NMR peak is much further downfield (~9.0 ppm) than the protons in the amino group. Proton signals that are located further downfield is caused by the deshielding effect. The proton within the amide is closer to electronegative groups (nitrogen and oxygen on the carbonyl) which will pull the electron density away from the proton, thereby deshielding the proton. On the other hand, the protons are further away from these electronegative groups and therefore they are less deshielded.

4. Naproxen is a non-steroidal anti inflammatory drug, which is used to treat pain or inflammation caused by conditions such as arthritis, ankylosing spondylitis, tendinitis, bursitis, gout, or menstrual cramps. Consider the following Acid-Base Reaction:

a. Circle all functional groups in naproxen. Do we expect this compound to be water-soluble? justify your answer.

We can expect naproxen to be non-water soluble. Has two functional groups able to H-bond with water solvent, and 12 Carbons not in functional group. Therefore, it does not obey the “Rule of Five” and is not water-soluble.

b. Draw curved arrows for the reaction, and determine the products (redraw mechanism here).

c. Determine whether the products or reactants are favored. Justify your answer: (pKa of Naproxen = 4.15)

\[
\text{Pka of Naproxen (4.15) < pKa of Water (15), products are favored}
\]
Ratio of products: reactants ⇒ roughly 1:10
Hint: Favors formation of more stable conjugate base

d. Say naproxen was halogenated at the aromatic rings (example shown below). What can we expect to happen to the acidity of naproxen? How will pKa change?

By the inductive effect, acidic hydrogen is destabilized by adding electron withdrawing groups to the ring. Thus, the acid is more acidic, and so pKa should theoretically decrease.

5. Consider the following S_N2 Reaction Mechanism (Nucleophilic Substitution):

a.) draw the transition state of the reaction mechanism. Include partial bonds and partial charges

See above. Note locations of partial bonds/partial charges

b.) Assuming the free energy of the reaction is negative, what can be inferred of the given reaction?

Reaction is spontaneous in the forward direction, therefore the products are favored over reactants.
(NOTE: this does not mean rate of forward reaction is greater than rate of backwards reaction, this depends on the concentration. (Le Chatelier's Principle)).

c.) draw the free energy diagram of the following reaction mechanism. Label the reactants, products, transition state, energy of activation.

d.) What does the free energy of the reaction say about the rate of the reaction?

Gibbs Free Energy value only determines the spontaneity of the reaction, but does not say anything about the reaction rate. Free Energy is a thermodynamic property, while the rate is a kinetic property.

Rate of reaction is determined by the energy of activation (Ea), as well as temperature