INTRODUCTION TO ORGANIC CHEMISTRY

First name (print): ___________________ Family name (print): ___________________
signature _________________________________________________________________
student # ________________________________________________________________

Section:
   ___ Section 02  MWF @ 8:30 am   Instructor: Dr. Michel Gravel
   ___ Section 04  MWF @ 9:30 am   Instructor: Dr. David Sanders
   ✓    Section 06  TR @ 10:00 am   Instructor: Dr. Pearson Ahiahonu
   ___ Section 96, C10, or C16 (off-campus)   (Dr. A. Szmigielski, Dr. J. Thompson)

• This is a 2-hour, closed-book examination.
• No calculators, phones or electronic devices are permitted. Molecular models are allowed.
• Answers to short answer questions must be written directly in this booklet.
• Answers to multiple choice questions must be entered on the opscan sheet with an HB pencil. **ONLY one answer per multiple choice question is correct!**
• Use the back pages of this examination booklet as scratch paper.
• This exam has 14 pages, including the periodic table and pKa table on the last page.
• **Remember to fill in the top of this page as well as your student number and name on the opscan sheet!**
• **Part II of this exam needs to be filled in this booklet directly.**
• **HAND IN ALL your material (this booklet, and the opscan sheet).**

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PART I

i. Write your name on the opscan sheet.

ii. Write your student ID# AND darken the corresponding circles on the opscan sheet.

Circle the best answer on the question page and fill in the answer on the blue optical scan sheet.

1. The hybridization of each carbon atom (from left to right) in the following molecule is:

   \[
   \begin{align*}
   &\text{sp}^2, \text{sp}^2, \text{sp}^3, \text{sp}^3 \\
   &\text{sp}^3, \text{sp}^2, \text{sp}^3, \text{sp}^2 \\
   &\text{sp}^3, \text{sp}, \text{sp}^3, \text{sp}^2 \\
   &\text{sp}^2, \text{sp}^2, \text{sp}^2, \text{sp}^3 \\
   \end{align*}
   \]

2. What is the relationship between these two molecules?

   \[
   \begin{align*}
   &\text{Identical} \\
   &\text{Constitutional isomers} \\
   &\text{Enantiomers} \\
   &\text{Diastereomers}
   \end{align*}
   \]

3. How many sigma (σ) bonds and pi (π) bonds are there in the following molecule?

   \[
   \begin{align*}
   &\text{9 sigma bonds and 3 pi bonds} \\
   &\text{13 sigma bonds and 0 pi bonds} \\
   &\text{10 sigma bonds and 3 pi bonds} \\
   &\text{10 sigma bonds and 2 pi bonds}
   \end{align*}
   \]
4. How many lone \textbf{pairs} of electrons are present in the following molecule?

\[
\begin{array}{c}
\text{NH}_2 \\
\text{OH} \\
\text{C} \\
\end{array}
\]

\begin{enumerate}
\item a. 3
\item b. 4
\item c. 5
\item d. 6
\end{enumerate}

5. Which of these compounds form hydrogen bonds?

\[
\begin{array}{cccc}
\text{OH} & \text{SH} & \text{NH}_2 & \text{PH}_2 \\
\text{I} & \text{II} & \text{III} & \text{IV} \\
\end{array}
\]

\begin{enumerate}
\item a. I only
\item b. I and II
\item c. III and IV
\item d. I and III
\end{enumerate}

6. What functional groups are present in the following molecule?

\[
\begin{array}{c}
\text{aldehyde} \\
\text{(OH) alcohol} \\
\text{alkene, ketone, alcohol, aldehyde, carboxylic acid} \\
\text{alkene, ketone, aldehyde, alcohol} \\
\text{alkene, ketone, carboxylic acid} \\
\text{alkene, ketone, carboxylic acid, alcohol, aldehyde}
\end{array}
\]
7. Which of the following is the most important factor in assessing the significance of a resonance form?
   
   a. The fewest number of formal charges
   b. The largest spread of like formal charges
   c. The most atoms with full octets
   d. The negative charges on the most electronegative atoms
   e. A separation between the positive and negative charges

8. What is(are) the product(s) resulting from the following movement of electrons?

Reaction:

\[ \text{Product A} \quad \text{Product B} \]

\[ \text{Product C} \quad \text{Product D} \]

\[ \text{Product E} \quad \text{Product F} \]
Questions 9 and 10 refer to the following figure. The structure of caffeine is shown in the centre, along with two different resonance structures I and II with lone pairs and formal charges omitted.

9. How many lone pairs of electrons can be found on the oxygen at A?
   a. 0
   b. 1
   c. 2
   d. 3
   e. That can’t be determined from the structure

10. What is the formal charge of the nitrogen at B?
    a. -1
    b. 0
    c. +1
    d. +2
    e. That can’t be determined from the structure

11. What is the product of the following reaction?

\[
\text{Cyclohexene} \xrightarrow{\text{H}_2, \text{Pd} / \text{C}} \text{Product}
\]
12. On what side of the equation does the equilibrium lie in the following reaction, and why? (You can refer to the pKa table on the last page.)

\[ \text{H}_2\text{O} + \text{SH} \rightleftharpoons \text{H}_3\text{O}^+ + \text{S}^- \]

- On the left, because water has a higher pKa than thioethane
- On the right, because water has a higher pKa than thioethane
- On the left, because hydronium has a lower pKa than thioethane
- On the right, because hydronium has a lower pKa than thioethane
- Equilibria require concentrations to be determined

13. What is the most acidic proton in the following molecule? (You can refer to the pKa table on the last page.)

14. Rank the following molecules in order of acidity (from least acidic to most acidic).

- I < II < III
- I < III < II
- II < I < III
- II < III < I
- III < I < II
- III < II < I
15. What is the product of the following reaction?

\[
\text{\text{Cyclohexane}} + \text{Acetone} \rightarrow \text{Product A, B, C, D}
\]

i. \(\text{NaNH}_2, \text{Liq. NH}_3\)

ii. \(\text{NH}_4\text{Cl / H}_2\text{O}\)

---

16. Which structure below is correctly labelled with the \(R/S\) descriptors?

\[\text{A} \quad \text{B} \quad \text{C} \quad \text{D}\]

---

17. Markovnikov’s rule states that in the addition of \(\text{H-Cl}\) to an alkene, \(\text{H}\) will add to the alkene carbon with more \(\text{H}\)'s. This empirical rule can be explained by...

a. steric hindrance.
b. the \(pK_a\) of \(\text{H-X}\), which is lower than the \(pK_a\) of the alkene.
c. the stability of the carbocation intermediate.
d. hydrogen bonding.
e. nothing, it’s just a rule.

---

18. Which of the following Newman projections represents a conformer of hexane?

\[\text{A, B, C, D}\]
19. Which of the following 3 molecules are chiral?

- I and II
- II and III
- I, II and III
- II only
- none are chiral

20. Why is it not a good idea to form a Grignard reagent in methanol?

- Because methanol is nucleophilic due to lone pairs on the oxygen atom
- Because methanol has a high boiling point
- Because methanol is too acidic
- Because methanol can be oxidized to acetic acid
- It is a good idea to form a Grignard reagent in methanol.

21. Rank the following carbocations in order of decreasing stability (most stable to least stable):

- II > I > III
- I > II > III
- III > II > I
- II > III > I
- I > III > II
22. Which one of the following statements is true?

In the most stable chair conformation for cis-1-methyl-2-isopropylcyclohexane...
- both the methyl and the isopropyl groups are in the equatorial position
- both the ethyl and the isopropyl groups are in the axial position
- the methyl group is in equatorial position and the isopropyl group is in the axial position
- the methyl group is in the axial position and the isopropyl group is in the equatorial position

23. Which one of the following molecules is meso?

![Molecule Images]

24. What is the correct IUPAC name for this molecule?

![Molecule Image]

- (2E, 4E)-2-isopropyl-4-methylhexa-2,4-diene
- (2Z, 4E)-2-isopropyl-4-methylhexa-2,4-diene
- (2E, 4E)-4,5,6-trimethylhepta-2,4-diene
- (2Z, 4E)-4,5,6-trimethylhepta-2,4-diene
- (2E, 4Z)-4,5,6-trimethylhepta-2,4-diene

25. Which of the following reagents will convert an alkene to an epoxide?

- OsO₄ followed by NaHSO₃
- K₂CrO₄/H₂SO₄
- CH₃CO₂H
- Hg(OAc)₂
- PCC
PART II

1. (10 marks) For each reaction, draw the expected major organic product(s). Clearly indicate the appropriate stereochemistry where necessary.

a. 
\[
\overset{\text{i. BH}_3}{\text{ }} \quad \overset{\text{ii. H}_2\text{O}_2, \text{ NaOH}}{\text{ }}
\]
Anti-Markovnikov Addition of OH to alkene

b. 
\[
\overset{\text{Br}_2, \text{ H}_2\text{O}}{\text{ }}
\]
Addition of Bromine water to an alkene

c. 
\[
\overset{\text{i. CH}_3\text{CH}_2\text{I, Mg, ether}}{\text{ }} \quad \overset{\text{ii. H}_3\text{O}^+ \text{ workup}}{\text{ }}
\]
Grignard Reaction

d. 
\[
\overset{\text{i. NaBH}_4}{\text{ }} \quad \overset{\text{ii. H}_3\text{O}^+ \text{ workup}}{\text{ }}
\]
Oxidation addition to a carbonyl group

e. 
\[
\overset{\text{Cl}_2}{\text{ }}
\]
Addition of a halo to an alkene
2. (5 marks) For each of the following, draw two significant contributing resonance structures in the boxes provided (note: moving around only the electrons in the ring does not count; include groups connected to the ring in resonance).

a.

b.
3. (5 marks)

a) Complete the boxed structures by adding the missing substituents on the ring and using hashed (••••) and wedged (→) bonds.

\[ \text{HO} \quad \text{Cl} \quad \text{Br} \quad \text{H}_2\text{N} \quad \text{CH}_3 \quad \text{OH} \]

b) Complete the Newman projection in the box on the right by adding the 5 missing substituents. Make sure that the conformation in the Newman projection is the same as the one shown on the left.
4. (5 marks)
Propose a reasonable mechanism for the following transformation. Make sure to include all necessary curved arrows, lone pairs, and formal charges.