

Please read and sign the Honor Code statement below:

I pledge that on my honor, as a University of Colorado at Boulder student, I have neither given nor received unauthorized assistance on this exam.

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Signature

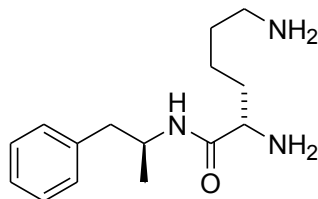
**General Instructions:** There are 9 pages and 19 questions, including this cover sheet. Be sure you have them all. Read each question carefully so that you know exactly what is being asked and what you need to write or draw. Your work on scratch pages will not be graded, so be sure everything you want graded is written on the exam itself.

Each multiple choice question (1-16) is worth **4 points and has only one correct answer**. Bubble in your answers to these questions on the Scantron provided. For the multiple choice questions, only the Scantron will be graded, not work on the exam. Good luck!

**PERIODIC CHART OF THE ELEMENTS**

| IA                  | IIA                | IIIB                | IVB                | VB                  | VIB                | VIIIB               | VIII               | IB                  | IIB                | IIIA                | IVA                 | VA                 | VIA                | VIIA                | INERT GASES        |                    |                    |
|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|--------------------|---------------------|---------------------|--------------------|--------------------|---------------------|--------------------|--------------------|--------------------|
| 1<br>H<br>1.00797   |                    |                     |                    |                     |                    |                     |                    |                     |                    |                     |                     |                    |                    | 1<br>H<br>1.00797   | 2<br>He<br>4.0026  |                    |                    |
| 3<br>Li<br>6.939    | 4<br>Be<br>9.0122  |                     |                    |                     |                    |                     |                    |                     |                    |                     | 5<br>B<br>10.811    | 6<br>C<br>12.0112  | 7<br>N<br>14.0067  | 8<br>O<br>15.9994   | 9<br>F<br>18.9984  | 10<br>Ne<br>20.183 |                    |
| 11<br>Na<br>22.9898 | 12<br>Mg<br>24.312 |                     |                    |                     |                    |                     |                    |                     |                    |                     | 13<br>Al<br>26.9815 | 14<br>Si<br>28.086 | 15<br>P<br>30.9738 | 16<br>S<br>32.064   | 17<br>Cl<br>35.453 | 18<br>Ar<br>39.948 |                    |
| 19<br>K<br>39.102   | 20<br>Ca<br>40.08  | 21<br>Sc<br>44.956  | 22<br>Ti<br>47.90  | 23<br>V<br>50.942   | 24<br>Cr<br>51.996 | 25<br>Mn<br>54.9380 | 26<br>Fe<br>55.847 | 27<br>Co<br>58.9332 | 28<br>Ni<br>58.71  | 29<br>Cu<br>63.54   | 30<br>Zn<br>65.37   | 31<br>Ga<br>69.72  | 32<br>Ge<br>72.59  | 33<br>As<br>74.9216 | 34<br>Se<br>78.96  | 35<br>Br<br>79.909 | 36<br>Kr<br>83.80  |
| 37<br>Rb<br>85.47   | 38<br>Sr<br>87.62  | 39<br>Y<br>88.905   | 40<br>Zr<br>91.22  | 41<br>Nb<br>92.906  | 42<br>Mo<br>95.94  | 43<br>Tc<br>[99]    | 44<br>Ru<br>101.07 | 45<br>Rh<br>102.905 | 46<br>Pd<br>106.4  | 47<br>Ag<br>107.870 | 48<br>Cd<br>112.40  | 49<br>In<br>114.82 | 50<br>Sn<br>118.69 | 51<br>Sb<br>121.75  | 52<br>Te<br>127.60 | 53<br>I<br>126.904 | 54<br>Xe<br>131.30 |
| 55<br>Cs<br>132.905 | 56<br>Ba<br>137.34 | *57<br>La<br>138.91 | 72<br>Hf<br>178.49 | 73<br>Ta<br>180.948 | 74<br>W<br>183.85  | 75<br>Re<br>186.2   | 76<br>Os<br>190.2  | 77<br>Ir<br>192.2   | 78<br>Pt<br>195.09 | 79<br>Au<br>196.967 | 80<br>Hg<br>200.59  | 81<br>Tl<br>204.37 | 82<br>Pb<br>207.19 | 83<br>Bi<br>208.980 | 84<br>Po<br>(210)  | 85<br>At<br>(210)  | 86<br>Rn<br>(222)  |
| 87<br>Fr<br>(223)   | 88<br>Ra<br>(226)  | +89<br>Ac<br>(227)  | 104<br>Rf<br>(261) | 105<br>Db<br>(262)  | 106<br>Sg<br>(266) | 107<br>Bh<br>(262)  | 108<br>Hs<br>(265) | 109<br>Mt<br>(266)  | 110<br>?<br>(271)  | 111<br>?<br>(272)   | 112<br>?<br>(277)   |                    |                    |                     |                    |                    |                    |

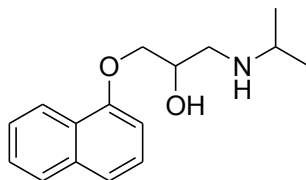
1. This is the structure of Vyvanse<sup>®</sup>, a compound used to treat attention deficit hyperactivity disorder (ADHD). Which of the following functional groups is present in this molecule?



Vyvanse<sup>®</sup>

- a. amine
- b. ester
- c. ketone
- d. ether
- e. alcohol

2. This is the structure of propranolol, a compound called a “beta blocker” that is used for the treatment of cardiac arrhythmias. Which of the following functional groups is present in this molecule?

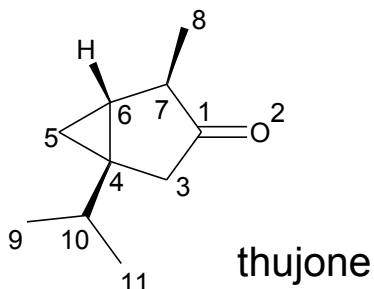


Propranolol

- a. aldehyde
- b. ether
- c. carboxylic acid
- d. alkyne
- e. ketone

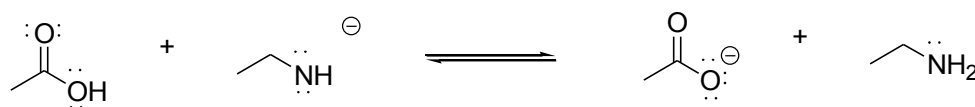
Questions 3-6 refer to thujone, the molecule shown below.

Thujone is a naturally occurring oil found in sage and other plants. It is a GABA receptor antagonist that causes convulsions in high doses. Use the numbering system on the structure to answer questions. Not all lone pairs are shown. All atoms are neutral.

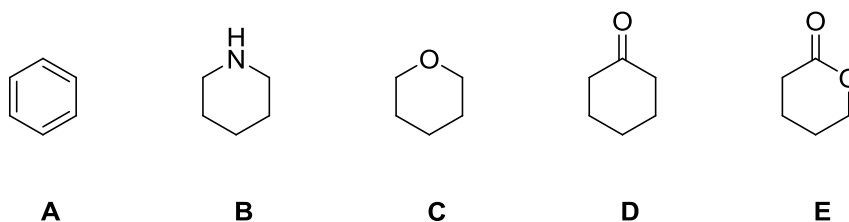


3. What is the hybridization of C-7?
  - a.  $sp$
  - b.  $sp^2$
  - c.  $sp^3$
  - d. C-7 is not hybridized.
  
4. Because of the functional group it contains, this molecule is correctly classified as a:
  - a. ester
  - b. alcohol
  - c. ketone
  - d. ether
  - e. aldehyde
  
5. The geometry at C-3 is
  - a. tetrahedral
  - b. trigonal planar
  - c. linear
  - d. bent
  - e. none of these
  
6. What is the hybridization of O-2?
  - a.  $sp$
  - b.  $sp^2$
  - c.  $sp^3$
  - d. O-2 is not hybridized.

7. What is the equilibrium constant,  $K$ , for the forward reaction shown below? (Spectator ions are omitted for clarity.)



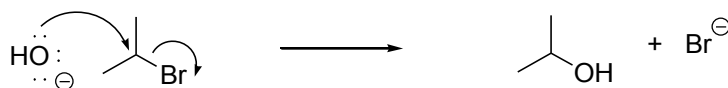
- a.  $10^{-31}$
  - b.  $10^{31}$
  - c.  $10^{-5}$
  - d.  $10^5$
  - e.  $10^9$
8. Which of the following compounds is an ester?



9.  $\text{NH}_3$  and  $\text{H}_2\text{O}$  are both Bronsted acids. We have explored stabilization in the conjugate base to explain acidity. For this pair of acids, which of the following ideas is the best to explain which conjugate base is more stable?

- a. The more stable conjugate base has more resonance stabilization.
- b. The more stable conjugate base has less resonance stabilization.
- c. The more stable conjugate base has its negative charge on a more electronegative atom than in the less stable conjugate base.
- d. The more stable conjugate base has its negative charge on a less electronegative atom than in the less stable conjugate base.
- e. The more stable conjugate base has its negative charge on an atom that is  $sp^2$  hybridized.

For questions 10 and 11, consider the reaction of sodium hydroxide and 2-bromopropane shown here. Hydroxide ion displaces bromide ion in a substitution reaction (the sodium spectator ion is not shown):



10. The frontier orbitals are the ones that interact in a chemical reaction. Which of these statements correctly identifies the frontier orbitals in this reaction?

- HOMO:  $sp^2$  on O in hydroxide  
LUMO:  $p$  on C in 2-bromopropane
- HOMO:  $sp^3$  on O in hydroxide  
LUMO:  $p$  on C in 2-bromopropane
- HOMO:  $p$  on C in 2-bromopropane  
LUMO:  $sp^3$  on O in hydroxide
- HOMO:  $sp^3$  on O in hydroxide  
LUMO: C-Br  $\sigma^*$  in 2-bromopropane
- None of these choices is correct

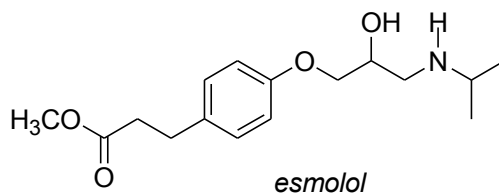
11. Which of the following is the best label for hydroxide in the reaction shown above?

- Electrophile
- Lewis acid
- Bronsted base
- Nucleophile
- Bronsted acid

12. Which of the following statements about the orbital interaction diagram for  $H_2$  is *false*?

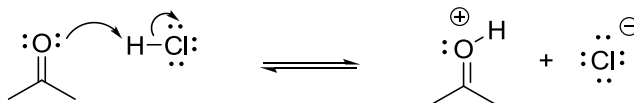
- There are two atomic orbitals that mix to produce two molecular orbitals.
- There is one bonding molecular orbital and one antibonding molecular orbital.
- The difference in energy between the bonding orbital and the atomic orbitals is the same as the difference in energy between the antibonding orbital and the atomic orbitals.
- The difference in energy between the bonding orbital and the atomic orbitals is less than the difference in energy between the antibonding orbital and the atomic orbitals.

13. This compound is esmolol, a drug used to treat high blood pressure.



Which statement is true?

- a. The proton in the OH group is more acidic than the proton in the NH group.
  - b. The proton in the NH group is more acidic than the proton in the OH group.
  - c. The protons on the CH<sub>3</sub>O group (shown at the left side of the molecule) are the most acidic protons in the molecule.
  - d. Esmolol contains an aldehyde functional group.
  - e. There are no  $sp^2$  hybridized atoms in esmolol.
14. What is the LUMO in the reaction shown below?



- a. 1s on H
  - b.  $sp^3$  on Cl
  - c. nonbonding orbital in the ketone
  - d. H-Cl  $\sigma$
  - e. H-Cl  $\sigma^*$
15. What is the percentage  $p$  character in an  $sp^3$  orbital?
- a. 25%
  - b. 33.3%
  - c. 50%
  - d. 66.7%
  - e. 75%

16. What are the formal charges on each of the non-hydrogen atoms in the compounds shown?

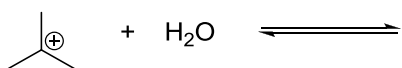


From left to right, the formal charges are:

- a. 1-, 1+, 0, 1-
- b. 1+, 0, 1+, 1-
- c. 0, 0, 1+, 0
- d. 0, 0, 0, 0
- e. 1-, 0, 1-, 1+

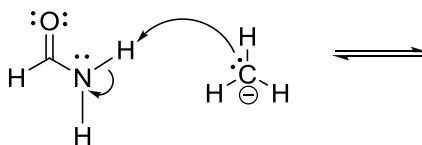
17. Draw all the constitutional isomers of pentane *using bond line formulas* (that is, do not explicitly draw "C's"). (6 pts)

18. Predict the product and draw a mechanism for the reaction between the Lewis acid and Lewis base shown. Include all necessary curved arrows, electron pairs, and non-zero formal charges. (10 pts)





19. a. Draw the products of the mechanism shown here. (Hint: There are two products.) (10 pts)



- b. One of the products has at least one additional resonance contributor. Draw this additional contributor and put a circle around *the more stable resonance contributor*. (Start by redrawing the appropriate product from part “a” above, then draw the resonance contributor.) (10 pts)