Chapter 20
Ketones and Aldehydes

Review of Concepts

Fill in the blanks below. To verify that your answers are correct, look in your textbook at the end of Chapter 20. Each of the sentences below appears verbatim in the section entitled *Review of Concepts and Vocabulary*.

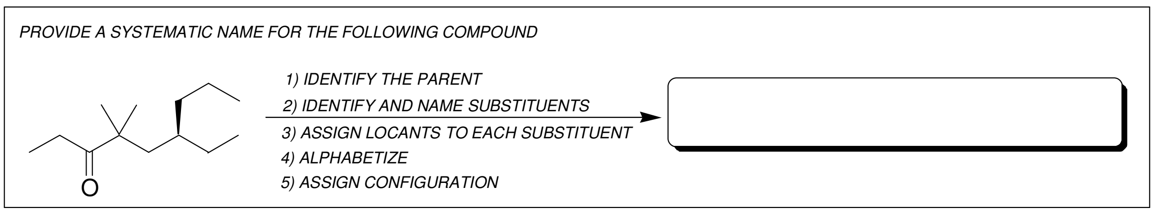
- The suffix "_____" indicates an aldehydic group, and the suffix "_____" is used for ketones.
- The electrophilicity of a carbonyl group derives from _____________ effects, as well as __________ effects.
- A general mechanism for nucleophilic addition under basic conditions involves two steps
  1) nucleophilic attack to generate a _____________ **intermediate**.
  2) _____________________
- The position of equilibrium is dependent on the ability of the nucleophile to function as a _______________.
- In acidic conditions, an aldehyde or ketone will react with two molecules of alcohol to form an __________.
- The reversibility of acetal formation enables acetals to function as _______________ groups for ketones. Acetals are stable under strongly _______ conditions.
- In acidic conditions, an aldehyde or ketone will react with a primary amine to form an _________.
- In acidic conditions, an aldehyde or ketone will react with a secondary amine to form an __________.
- In the **Wolff-Kishner reduction**, a hydrazone is reduced to an _________ under strongly basic conditions.
- In acidic conditions, all reagents, intermediates, and leaving groups either should be ____________ or should bear one ___________ charge.
- _________________ of acetals, imines, and enamines under acidic conditions produces ketones or aldehydes.
- In acidic conditions, an aldehyde or ketone will react with two equivalents of a thiol to form a ______________.
- When treated with Raney nickel, thioacetals undergo **desulfurization** to yield a ______________ group.
- When treated with a hydride reducing agent, such as lithium aluminum hydride (LAH) or sodium borohydride ($NaBH_4$), aldehydes and ketones are reduced to _______________.
- The reduction of a carbonyl group with LAH or $NaBH_4$ is not a reversible process, because hydride does not function as a ____________________.
- When treated with a Grignard agent, aldehydes and ketones are converted into alcohols, accompanied by the formation of a new ___________ bond.

- Grignard reactions are not reversible, because carbanions do not function as ___________________.
- When treated with hydrogen cyanide (HCN), aldehydes and ketones are converted into _______________. For most aldehydes and unhindered ketones, the equilibrium favors formation of the ___________________.
- The **Wittig reaction** can be used to convert a ketone to an _________.
- A **Baeyer-Villiger oxidation** converts a ketone to an __________ by inserting ______________________ next to the carbonyl group. Cyclic ketones produce cyclic esters called ________________.

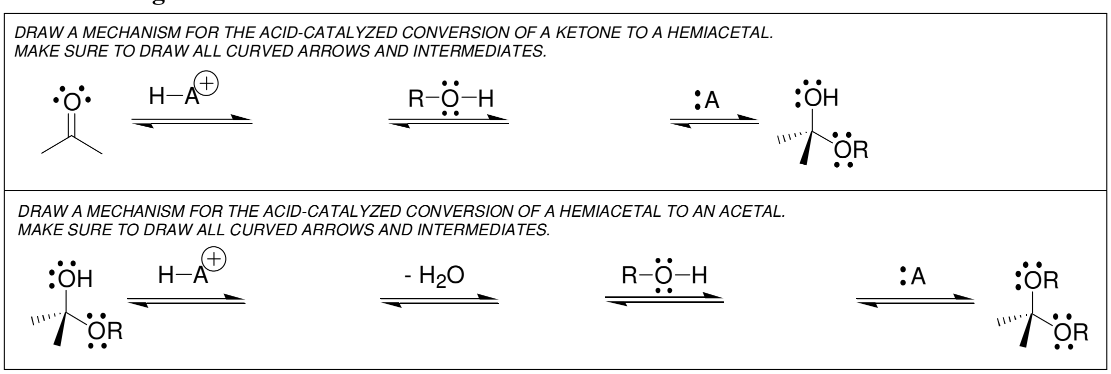
Review of Skills

Fill in the blanks and empty boxes below. To verify that your answers are correct, look in your textbook at the end of Chapter 20. The answers appear in the section entitled *SkillBuilder Review*.

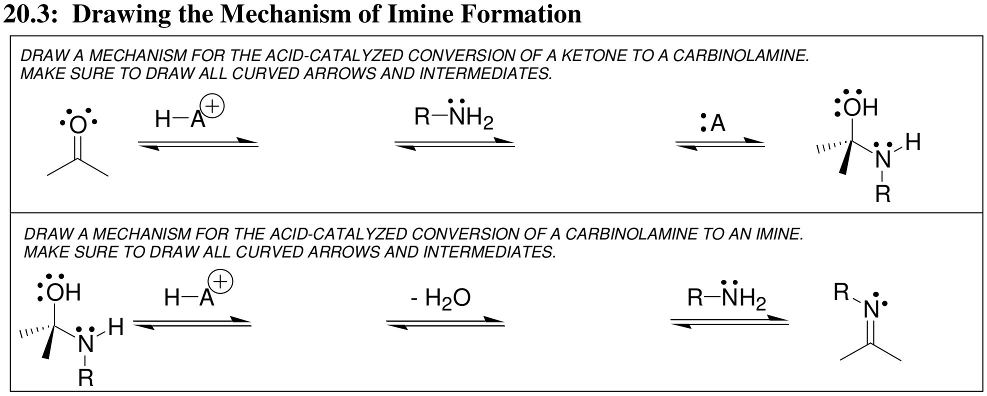
20.1: Naming Aldehydes and Ketones



20.2: Drawing the Mechanism of Acetal Formation

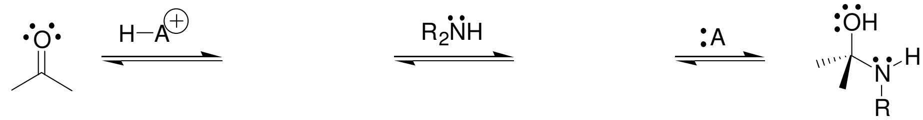


20.3: Drawing the Mechanism of Imine Formation

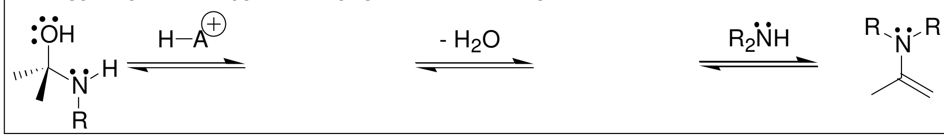


20.4: Drawing the Mechanism of Enamine Formation

DRAW A MECHANISM FOR THE ACID-CATALYZED CONVERSION OF A KETONE TO A CARBINOLAMINE. MAKE SURE TO DRAW ALL CURVED ARROWS AND INTERMEDIATES.



DRAW A MECHANISM FOR THE ACID-CATALYZED CONVERSION OF A CARBINOLAMINE TO AN ENAMINE. MAKE SURE TO DRAW ALL CURVED ARROWS AND INTERMEDIATES.

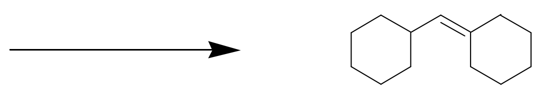


20.5: Drawing the Mechanism of a Hydrolysis Reaction

STEP 1 - *WORKING BACKWARDS, DRAW ALL ___________________.*	***STEP 2 -*** *DRAW ALL ___________ AND ___________________________________, USING THE FOLLOWING RULES:* *IN ACIDIC CONDITIONS, ALL REAGENTS, ____________________, AND ____________________ SHOULD EITHER BE NEUTRAL OR SHOULD BEAR ONE POSITIVE CHARGE.*

20.6: Planning an Alkene Synthesis with a Wittig Reaction

IDENTIFY THE REACTANTS YOU WOULD USE TO PREPARE THE FOLLOWING COMPOUND VIA A WITTIG REACTION:

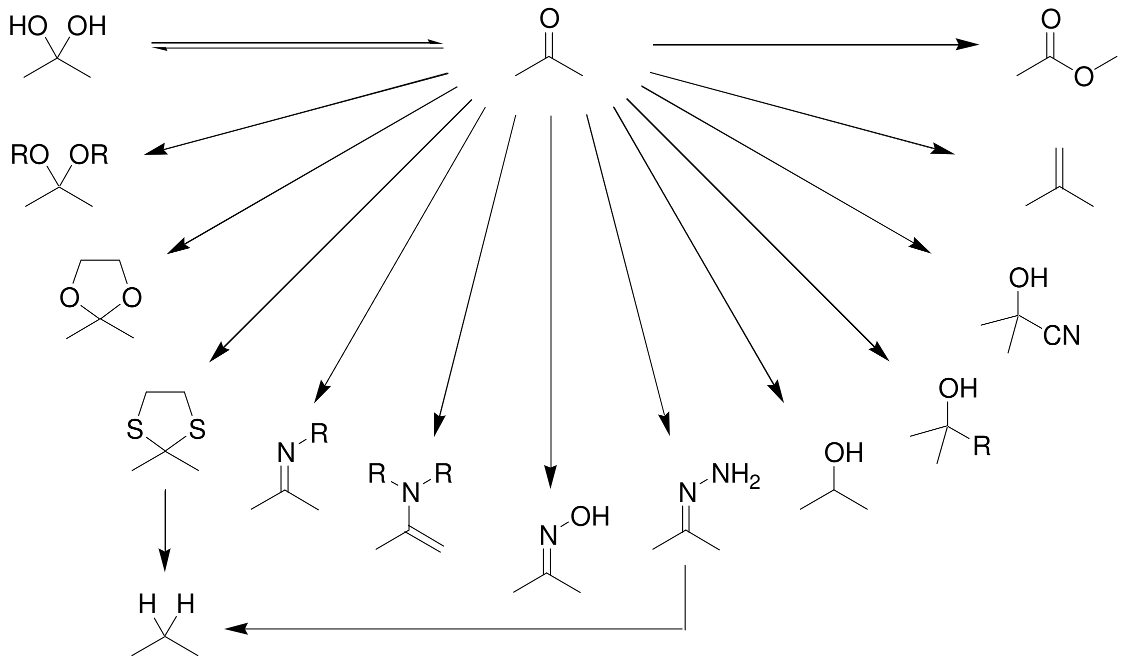


20.7: Proposing a Synthesis

BEGIN BY ASKING THE FOLLOWING TWO QUESTIONS: *1) IS THERE A CHANGE IN THE ____________________?* *2) IS THERE A CHANGE IN THE ____________________ ?*	*IF THERE IS A CHANGE IN THE CARBON SKELETON, CONSIDER ALL OF THE C-C BOND FORMING REACTIONS AND ALL OF THE C-C BOND BREAKING REACTIONS THAT YOU HAVE LEARNED SO FAR.* *<u>C-C BOND-FORMING REACTIONS IN THIS CHAPTER</u>:* - ________________ - ________________________ - ________________ *<u>C-C BOND-BREAKING REACTIONS IN THIS CHAPTER</u>:* - ________________________

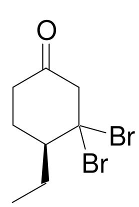
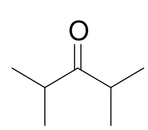
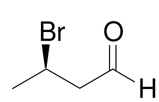
Review of Reactions

Identify the reagents necessary to achieve each of the following transformations. To verify that your answers are correct, look in your textbook at the end of Chapter 20. The answers appear in the section entitled *Review of Reactions*.



Solutions

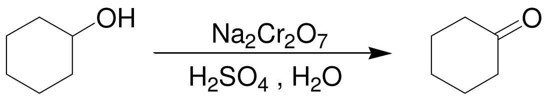
20.1. a) 5,5-dibromo-2,2-dimethylhexanal
b) (*3R,4S*)-3,4,5-trimethyl-2-hexanone
c) 2,2,5,5-tetramethylcyclopentanone
d) 2-propylpentanal
e) cyclobutanecarbaldehyde

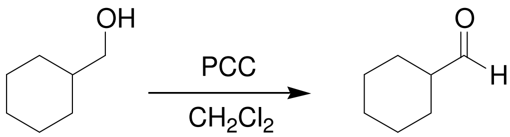
20.2. a)  b)  c) 

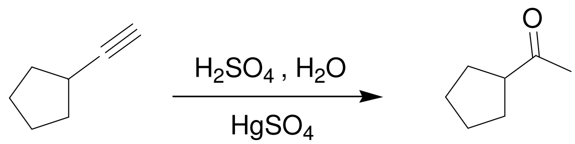
20.3. (*1S,4R*)bicyclo[2.2.1]heptan-2-one

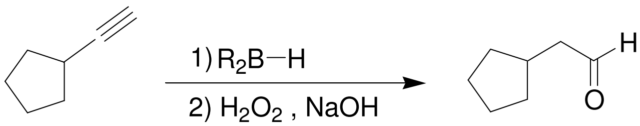
20.4. a) 1,3-cyclohexanedione b) 1,4-cyclohexanedione c) 2,5,8-nonanetrione

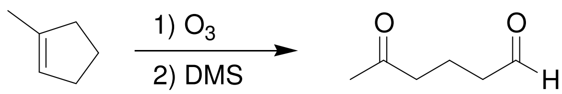
20.5.

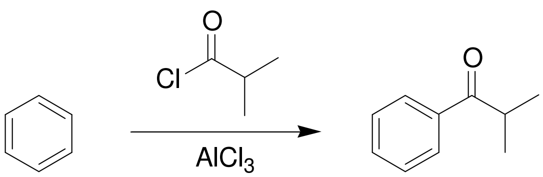
a) 

b) 

c) 

d) 

e) 

f) 

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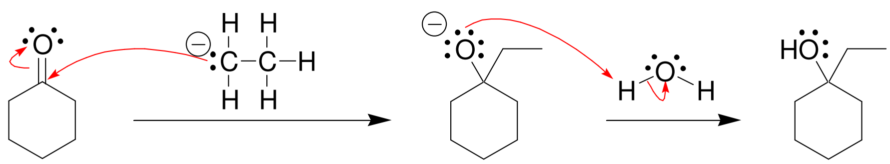
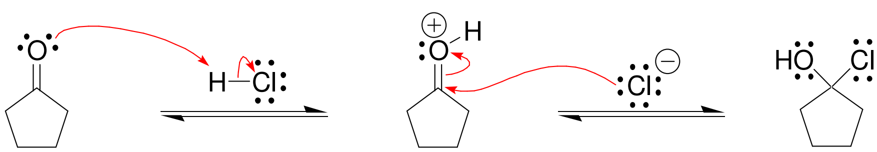
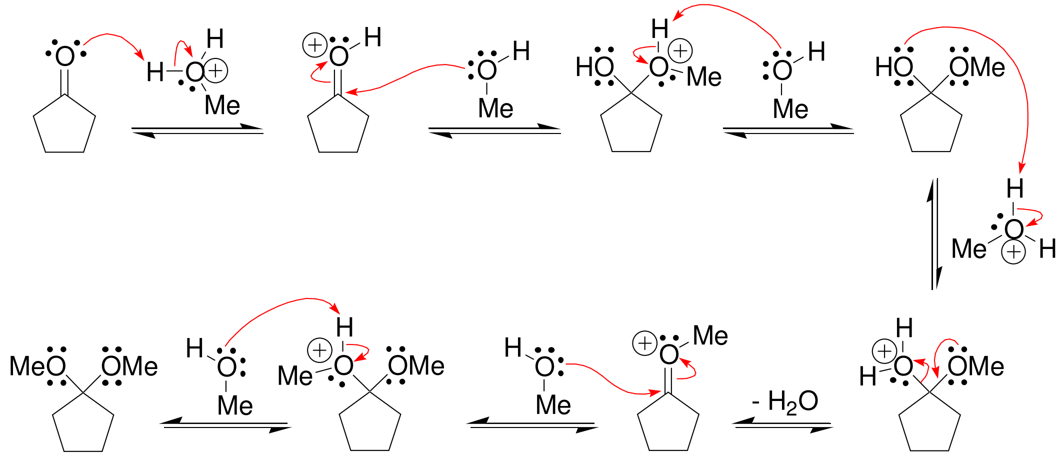
a) 

b) 

20.7. The carbonyl group in hexafluoroacetone is flanked by two very powerful electron-withdrawing groups (CF_3). These groups withdraw electron density from the carbonyl group, thereby increasing the electrophilicity of the carbonyl group. The resulting increase in energy of the reactant causes the equilibrium to favor the product (the hydrate).

20.8.

a)



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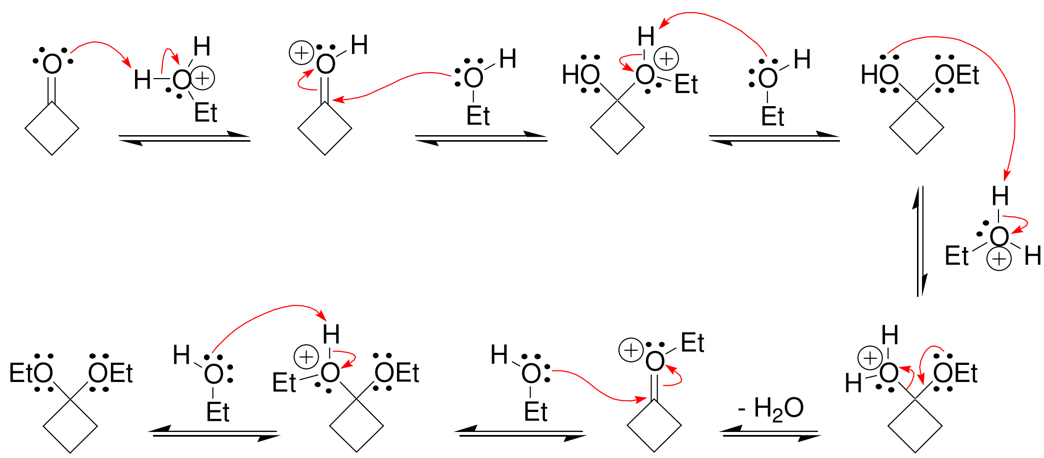

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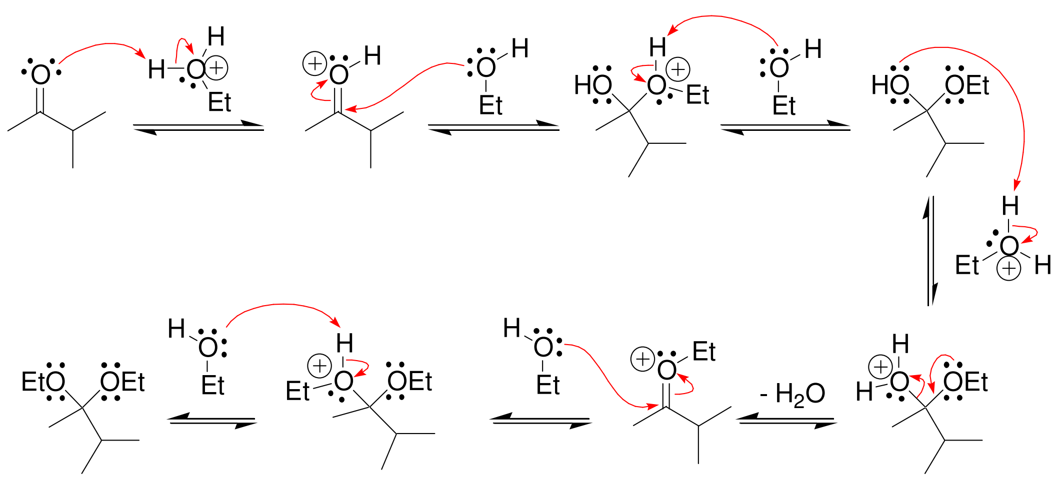

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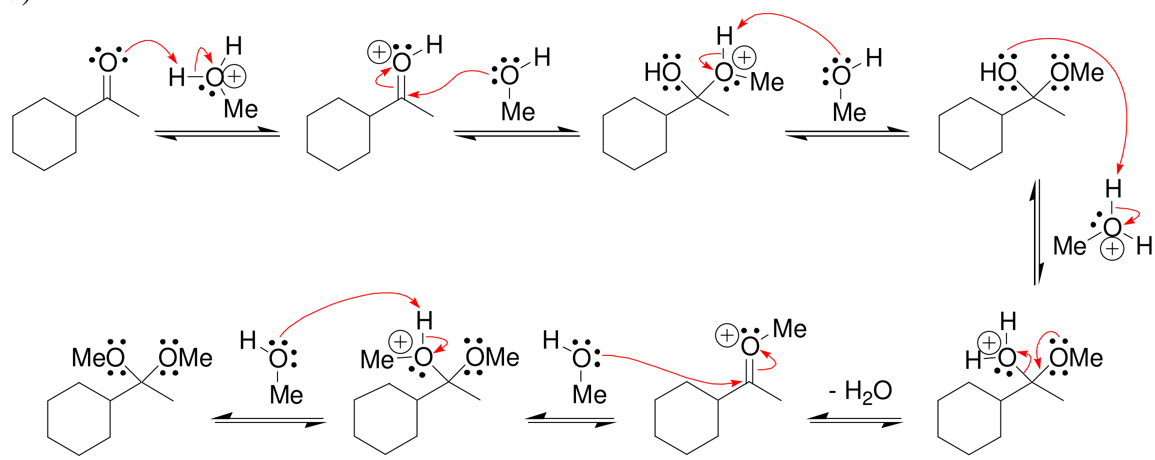

H
H–O⊕
Me
⊕
H
O
Me
HO
H
O⊕
Me
O
H
Me
HO
OMe
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Me
⊕
H
MeO
OMe
H
O
Me
Me–O⊕
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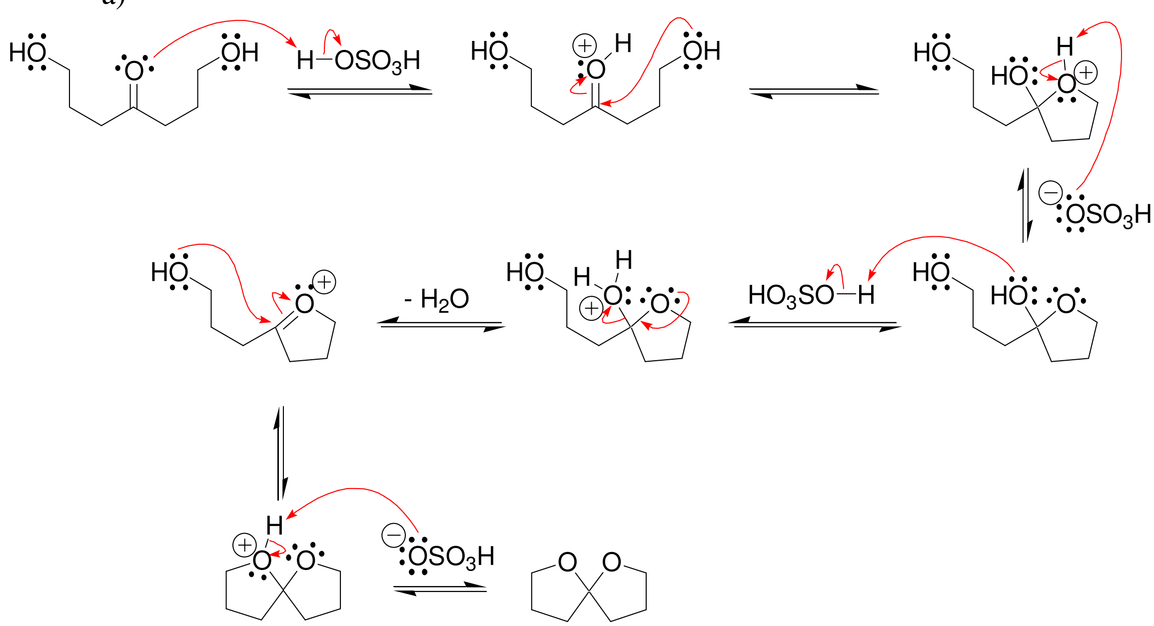
Me
- H₂O
H–O⊕
H
OMe

20.9.

a)



HO
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OH
H–OSO₃H
HO
⊕
O
H
OH
HO
HO
H
O⊕
⊖
OSO₃H
HO
O⊕
- H₂O
HO
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O
H
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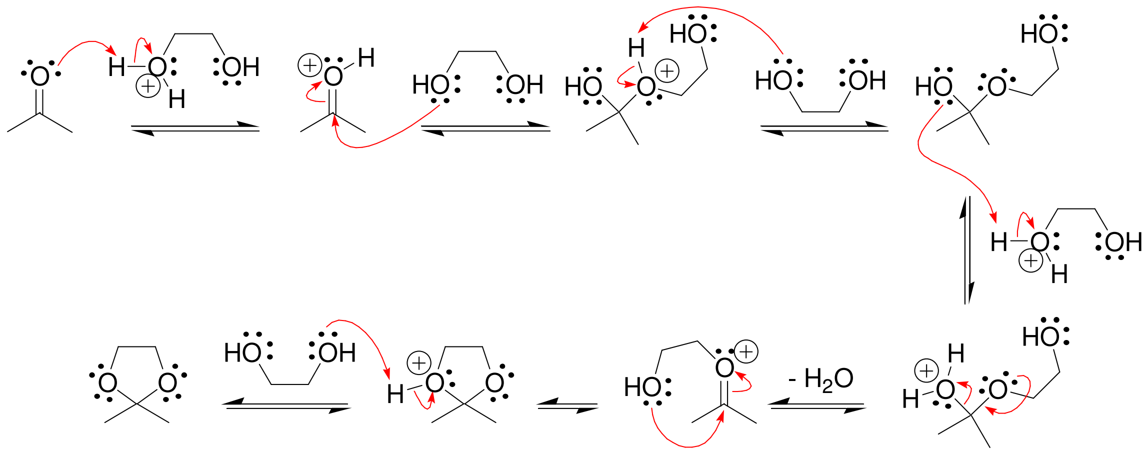
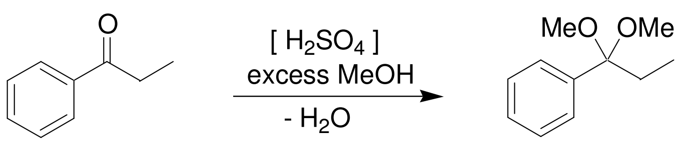
O
O
⊖
OSO₃H
O
O

b)



20.10.

a)



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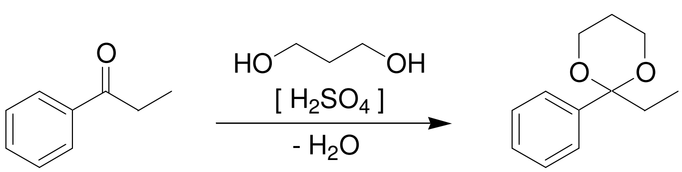
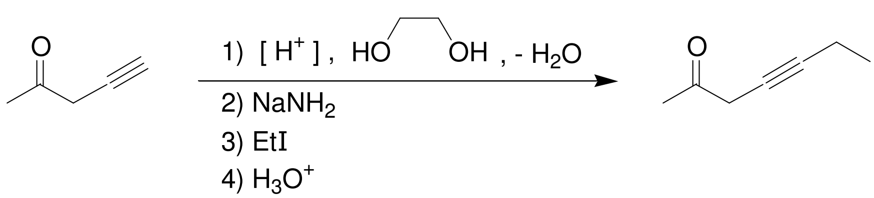


20.11.

a)



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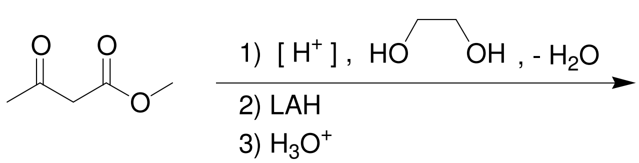

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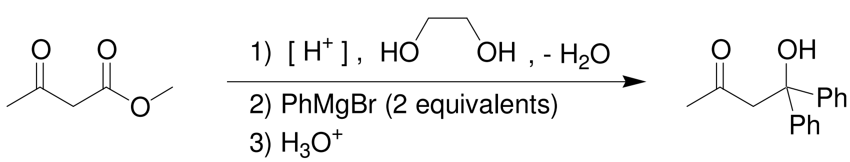
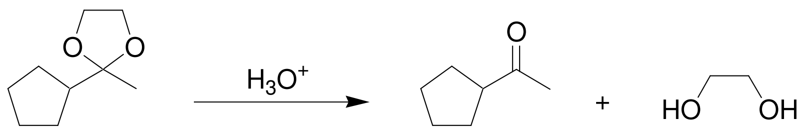


20.12. a)



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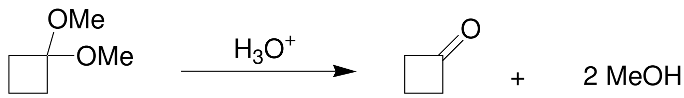

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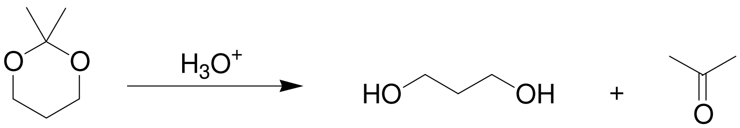

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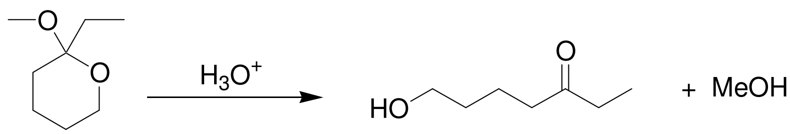

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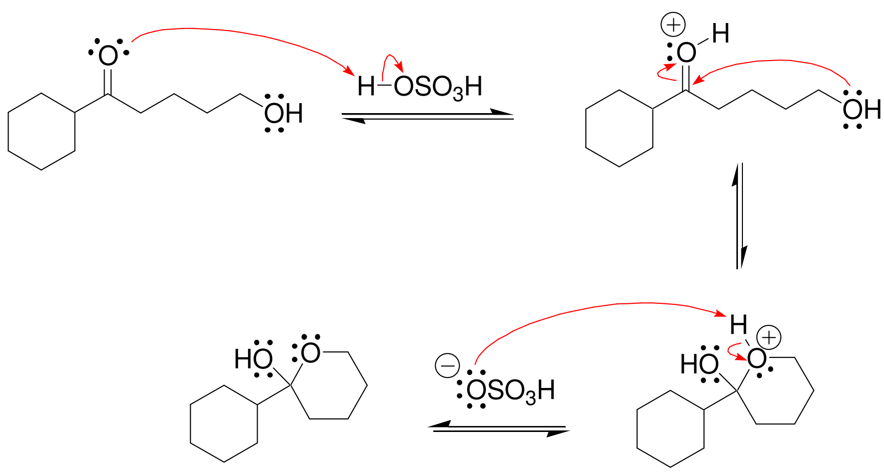
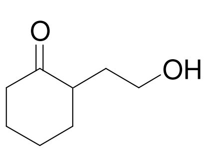
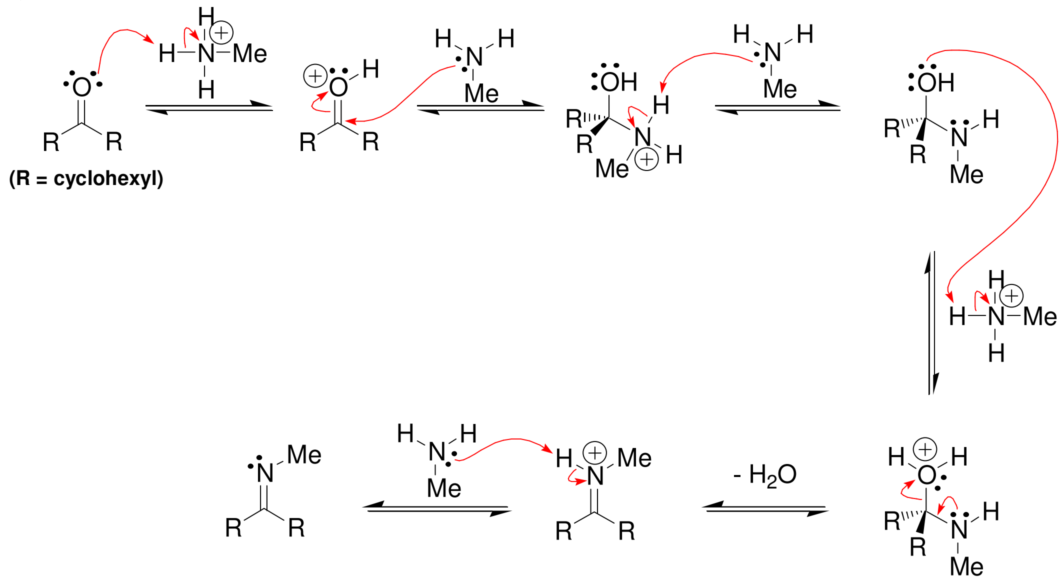


20.14.



20.15. Note: ***For each of the mechanisms shown below, the first two steps can be reversed (first the amine attacks the carbonyl group, and then the tetrahedral intermediate is protonated). It would be wise to check your lecture notes to determine if you instructor has a strong preference for this alternate sequence of steps.***

a)



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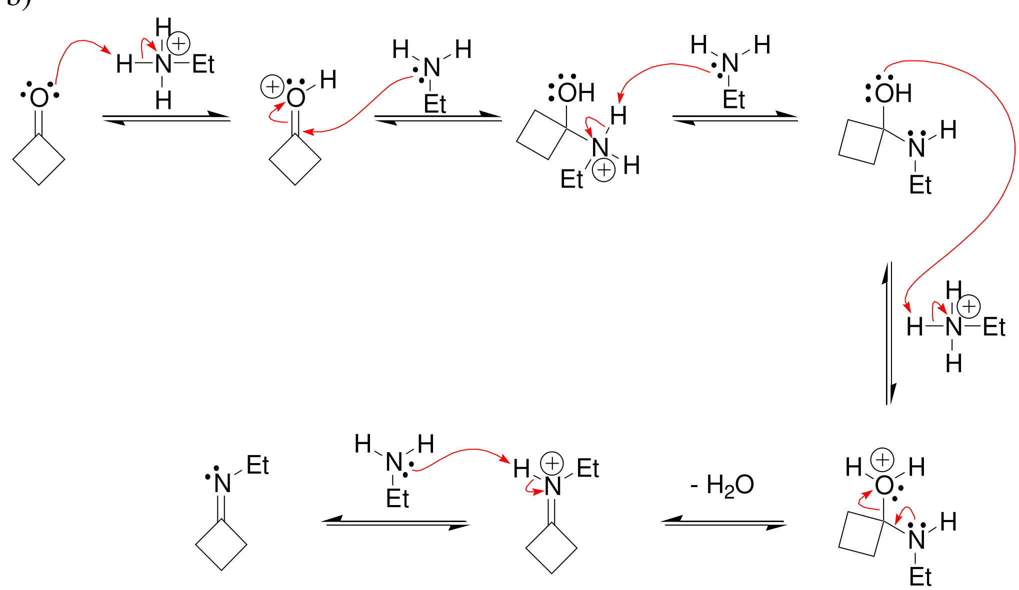

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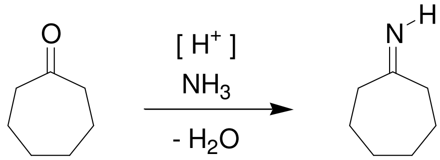
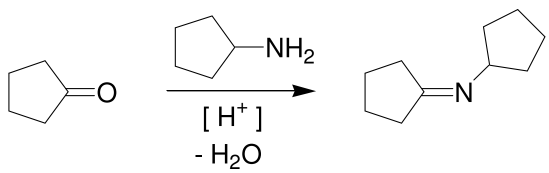
a) 

b) 

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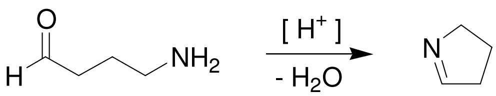
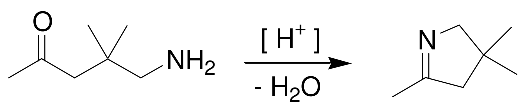
a) 

b) 

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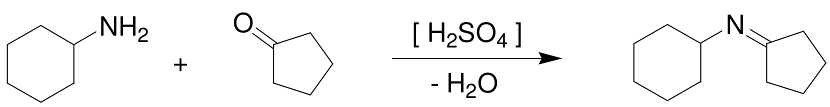
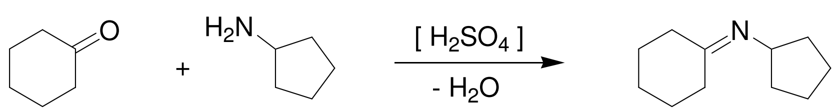
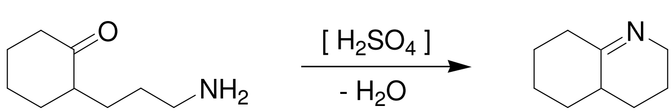
a) 

b) 

c) 

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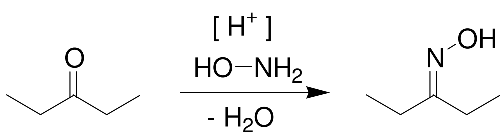
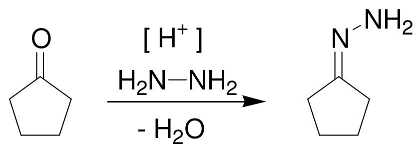
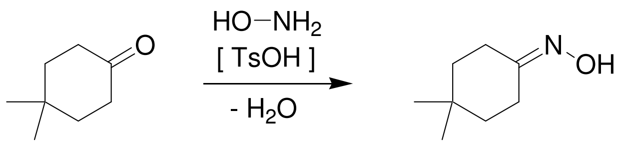
a) 

b) 

20.20.

a)



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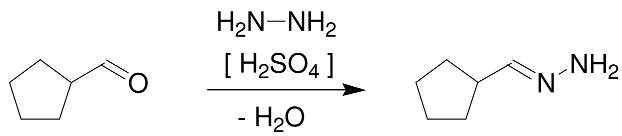
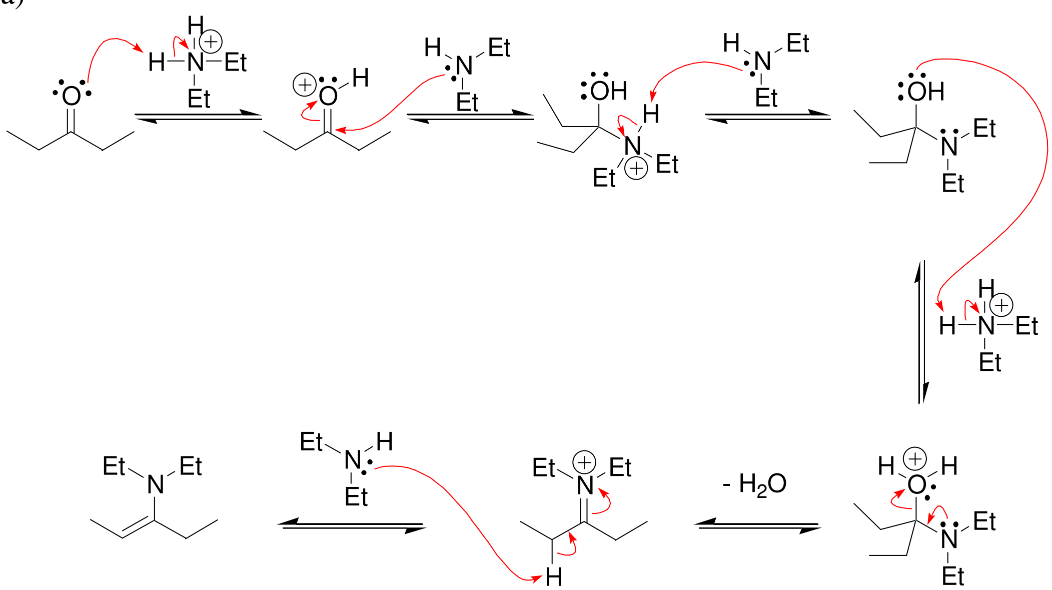


20.21. **Note**: ***For each of the mechanisms shown below, the first two steps can be reversed (first the amine attacks the carbonyl group, and then the tetrahedral intermediate is protonated). It would be wise to check your lecture notes to determine if you instructor has a strong preference for this alternate sequence of steps.***

a)



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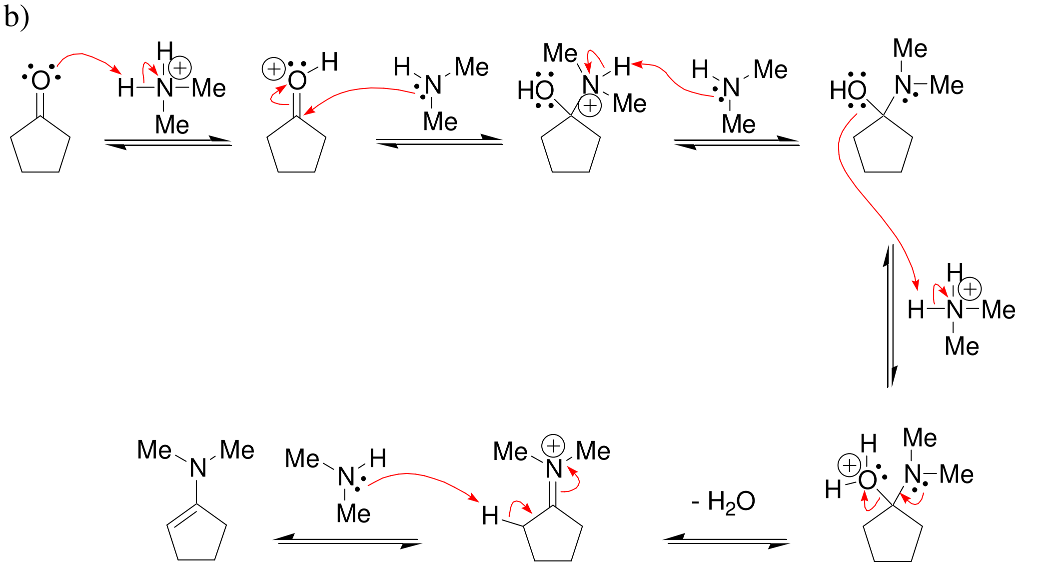

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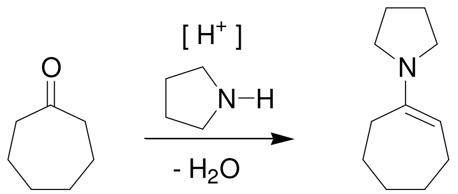
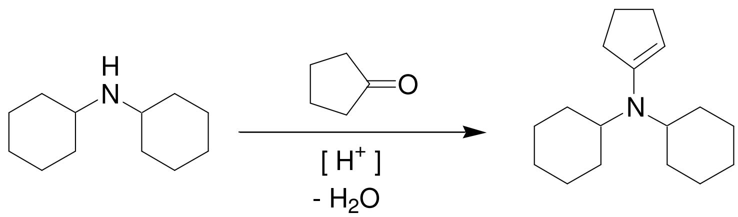
a) 

b) 

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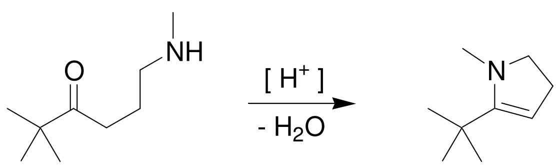
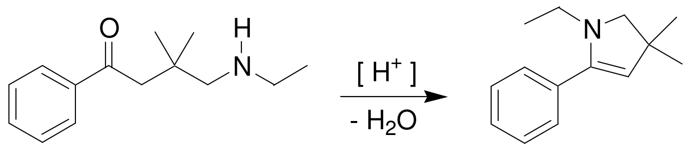
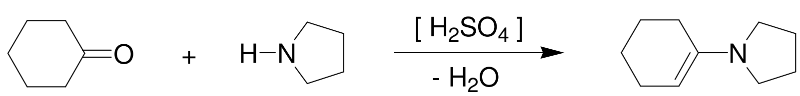
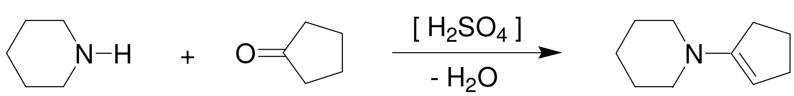
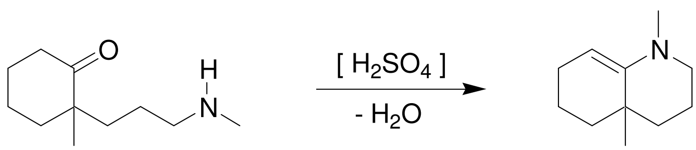
a) 

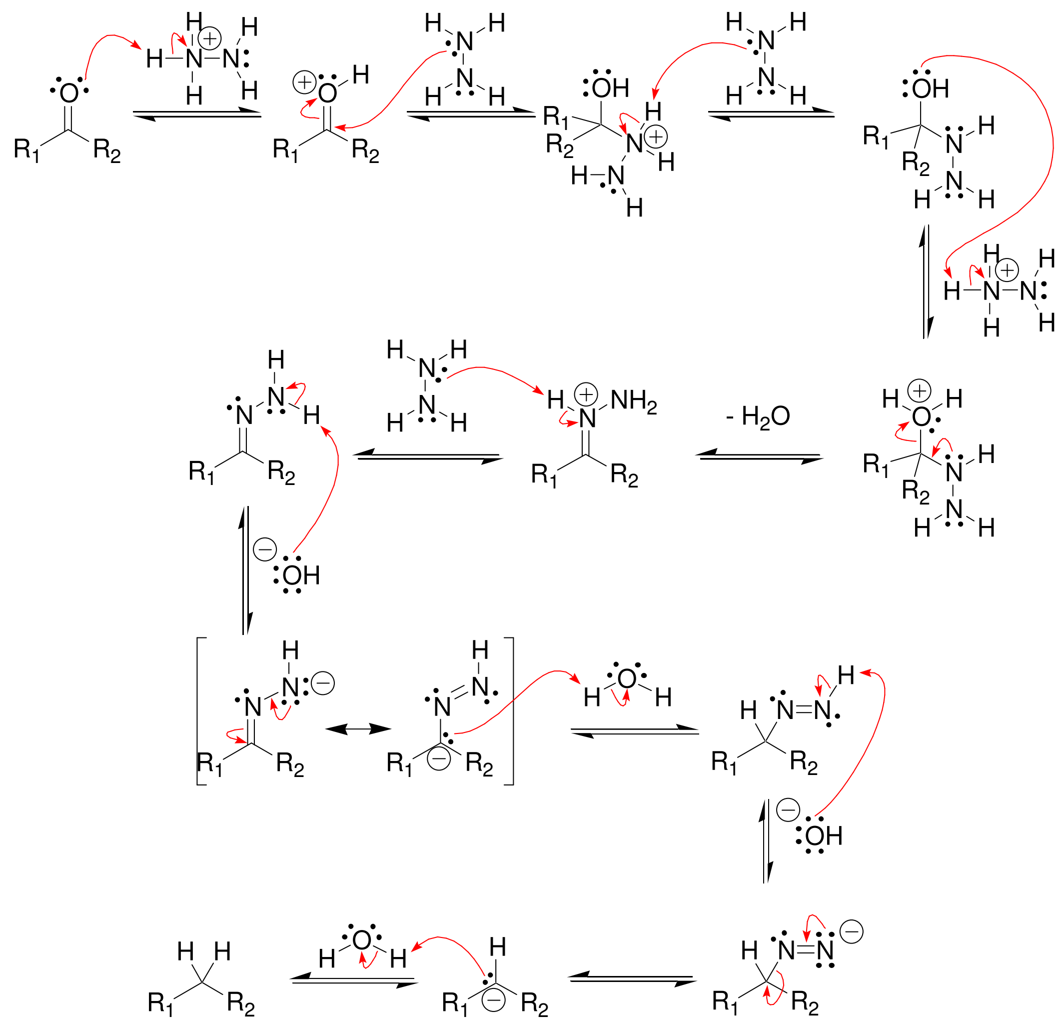
b) 

20.24. a) 

b) 

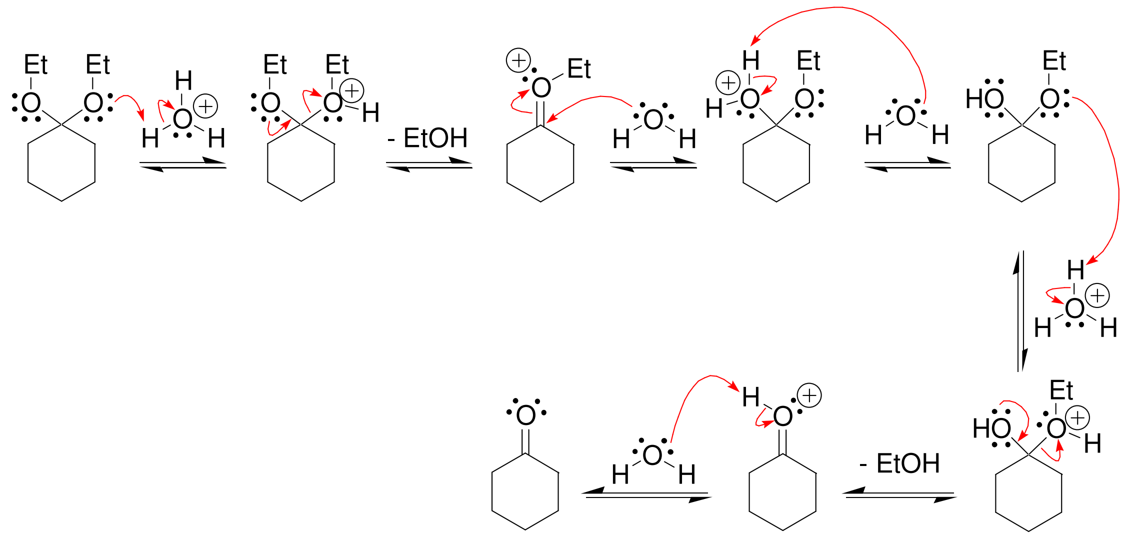
c) 

20.25. **Note**: ***The first two steps of this mechanism can be reversed (first the amine attacks the carbonyl group, and then the tetrahedral intermediate is protonated). It would be wise to check your lecture notes to determine if you instructor has a strong preference for this alternate sequence of steps.***

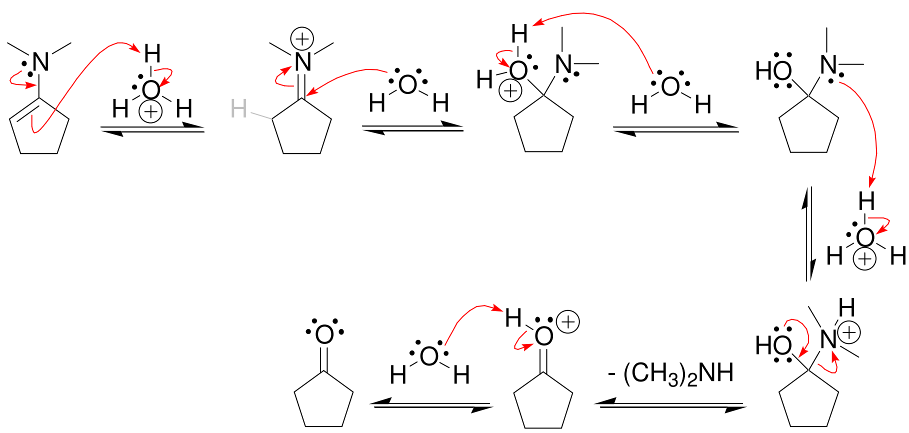


20.26.

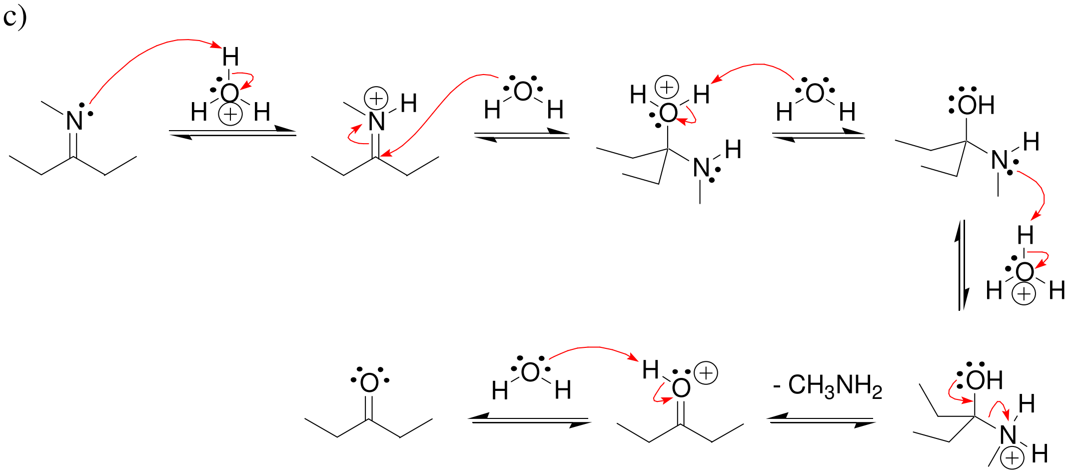
a)



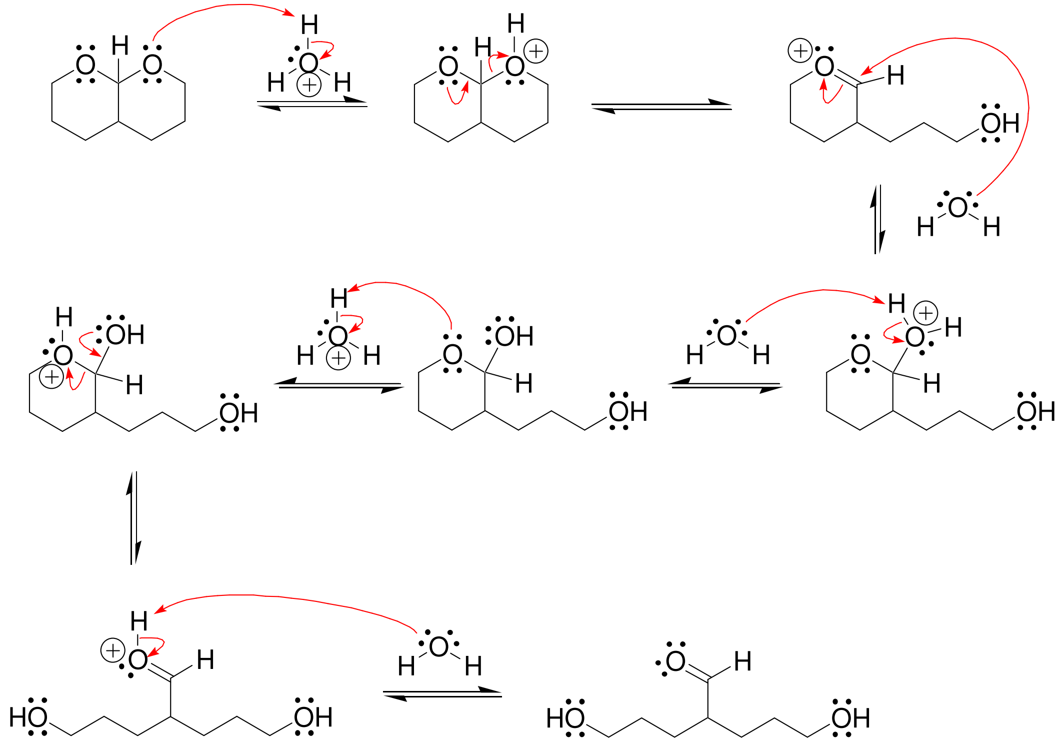
b)



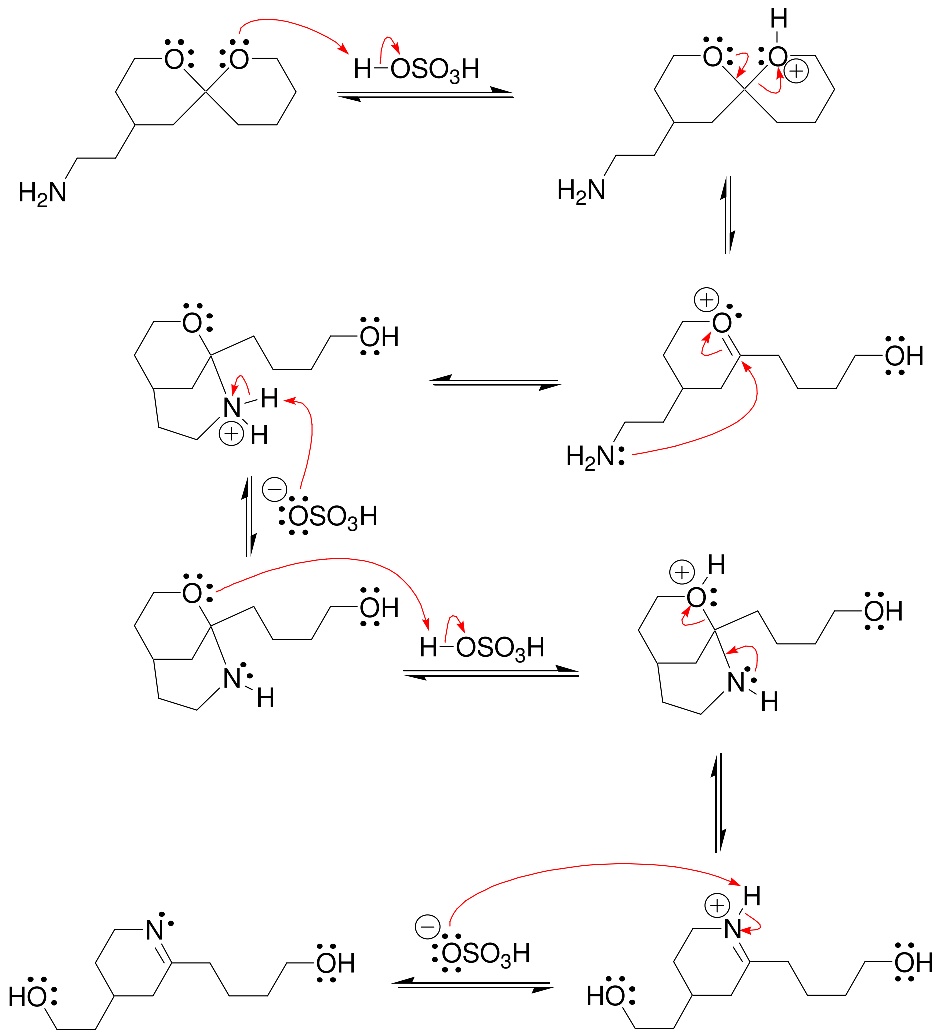
c)



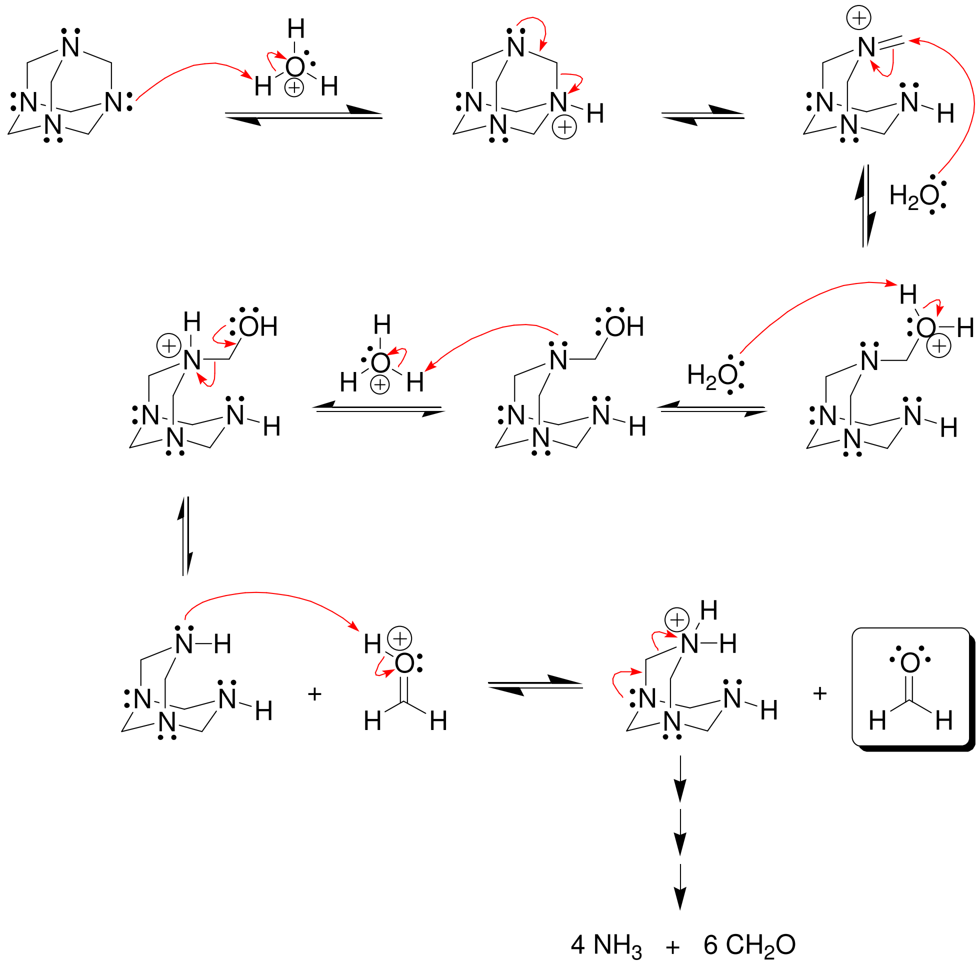
d)



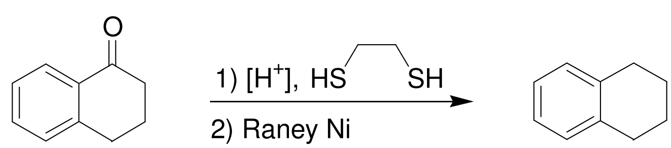
20.27.



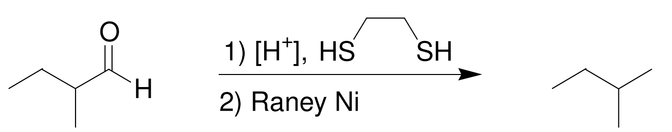
20.28.



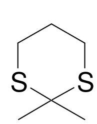
20.29. a)



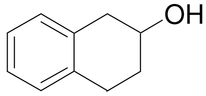
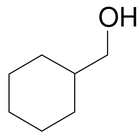
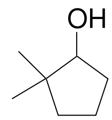
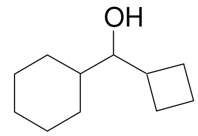
b)



20.30.

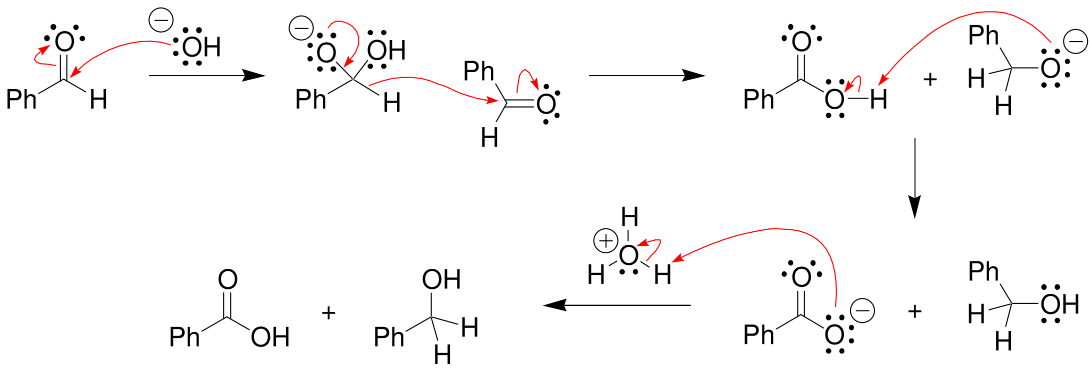


20.31.

a)  b)  c)  d) 

20.32.

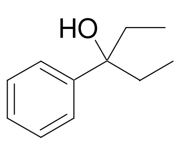
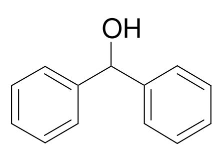
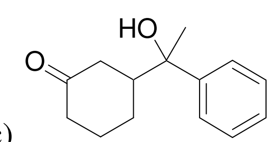
a) Below is a mechanism for the Cannizzaro reaction. After a hydroxide ion attacks one molecule of benzaldehyde, the resulting tetrahedral intermediate functions as a hydride delivery agent to attack another molecule of benzaldehyde, giving a carboxylic acid and an alkoxide ion. The alkoxide ion then deprotonates the carboxylic acid, generating a more stable carboxylate ion. This carboxylate ion is then protonated when an acid is added to the reaction mixture.



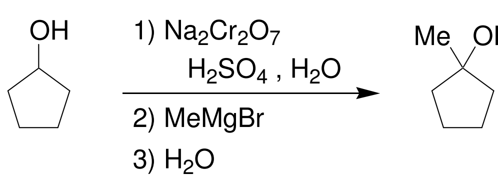
b) The function of H_3O^+ in the second step is to serve as a proton source to protonate the resulting carboxylate ion.

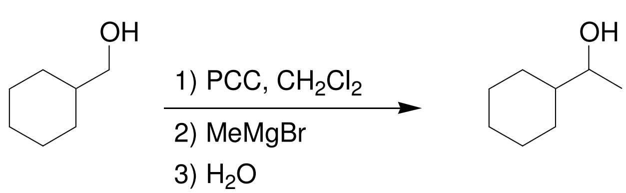
c) Water is only a weak acid (pK_a = 15.74), and is not sufficiently strong to serve as a proton source for a carboxylate ion (pK_a of PhCOOH is 4.21). See section 3.5 for a discussion of this topic.

20.33.

a)  b)  c) 

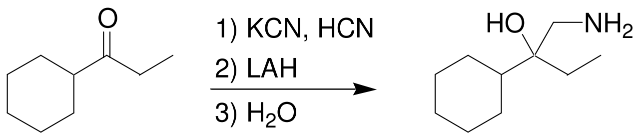
20.34.

a) 

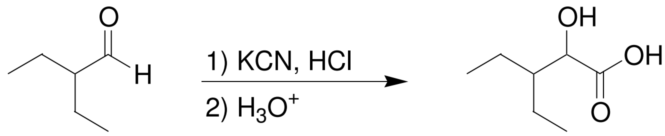
b) 

20.35.

a)

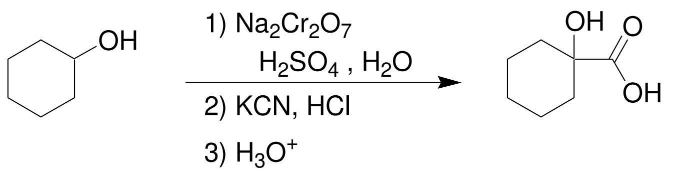


b)

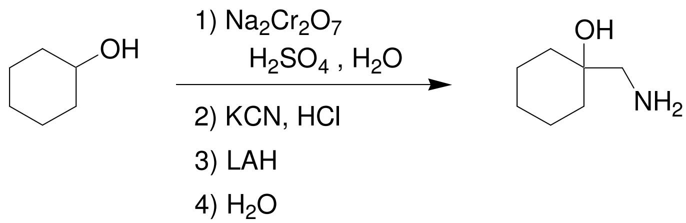


20.36.

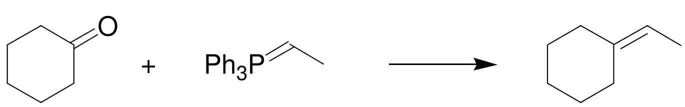
a)



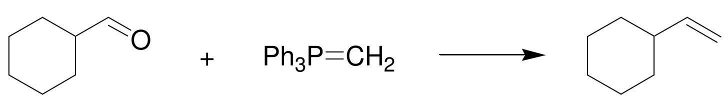
b)



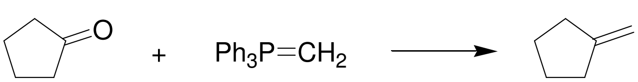
20.37. a)



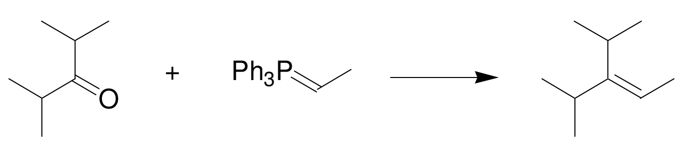
b)



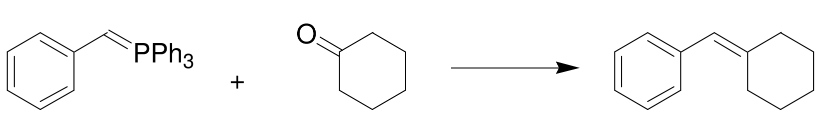
c)



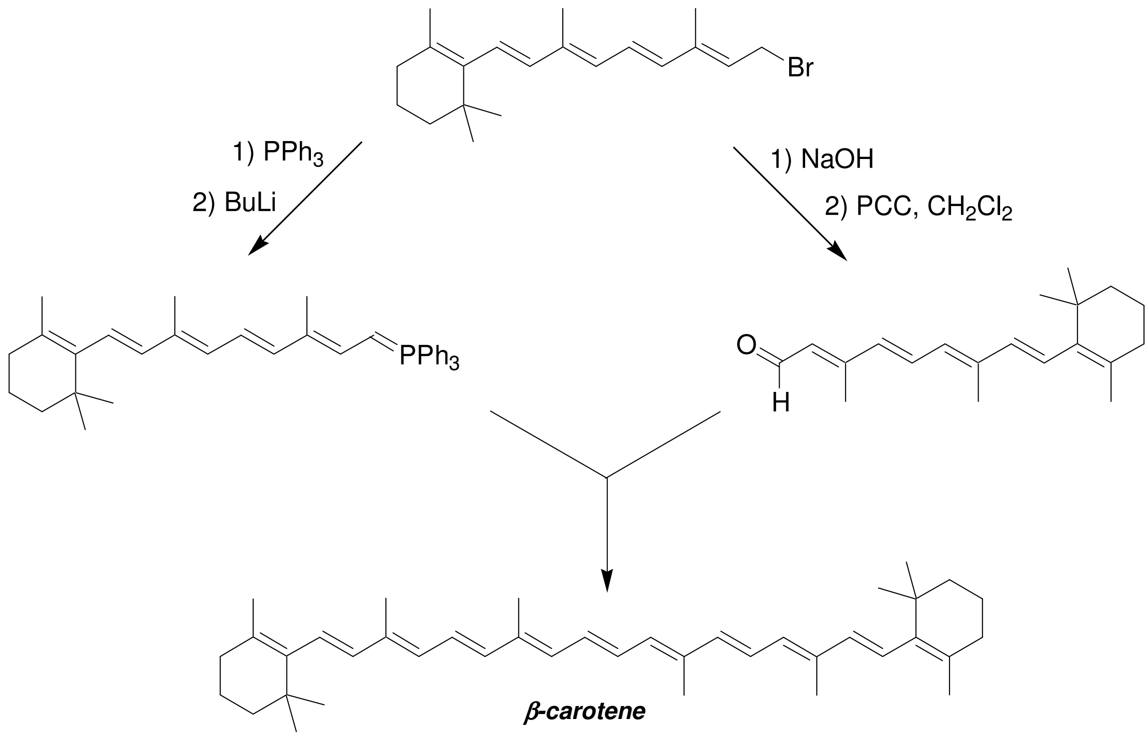
d)



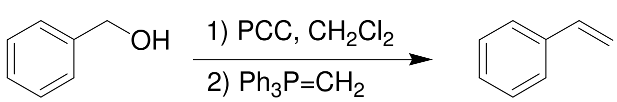
e)



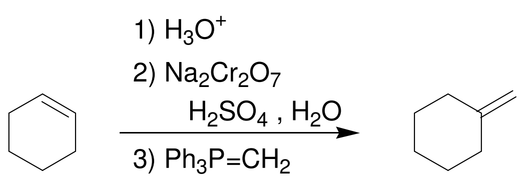
20.38.



20.39. a)

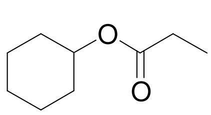


b)

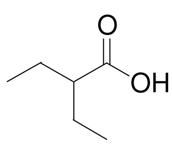


20.40.

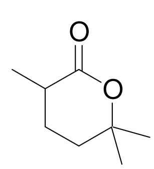
a)



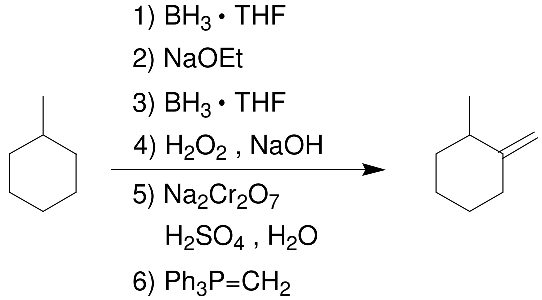
b)

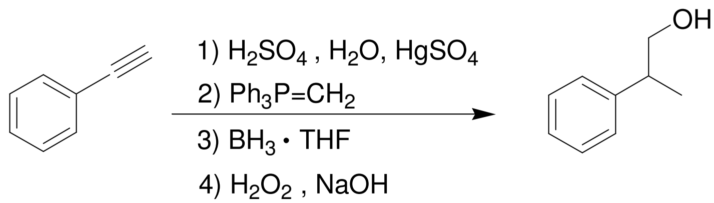


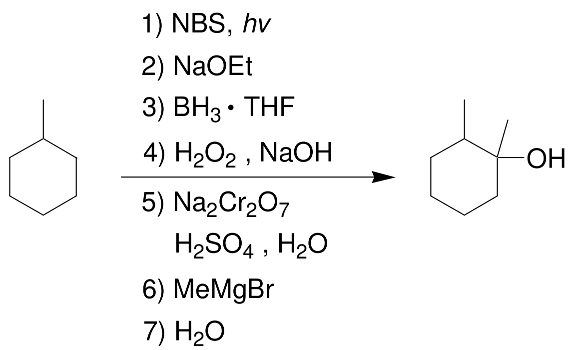
c)

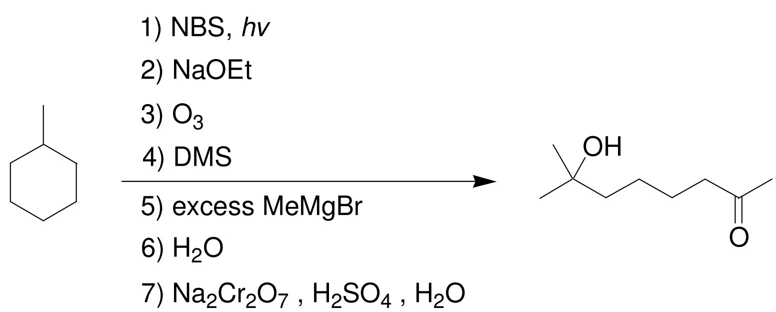


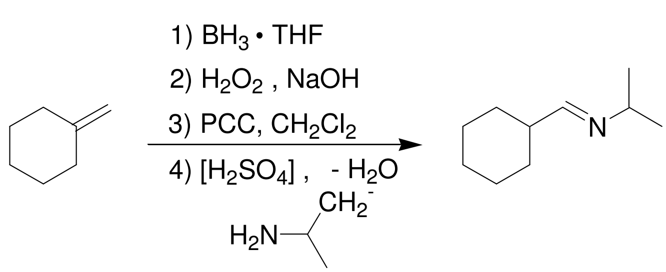
20.41.

a) 
1) BH3 • THF
2) NaOEt
3) BH3 • THF
4) H2O2 , NaOH
5) Na2Cr2O7
H2SO4 , H2O
6) Ph3P=CH2

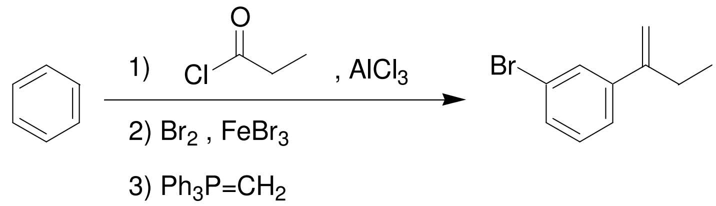
b) 
1) H2SO4 , H2O, HgSO4
2) Ph3P=CH2
3) BH3 • THF
4) H2O2 , NaOH
OH

c) 
1) NBS, hv
2) NaOEt
3) BH3 • THF
4) H2O2 , NaOH
5) Na2Cr2O7
H2SO4 , H2O
6) MeMgBr
7) H2O
OH

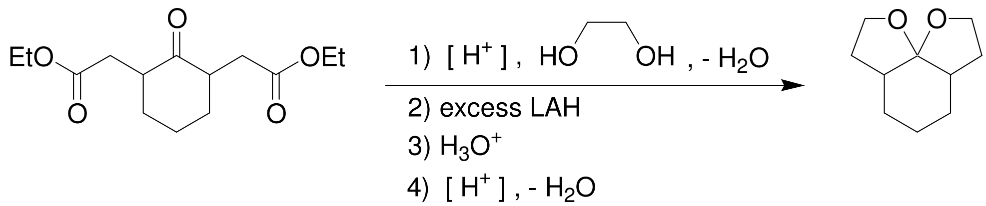
d) 
1) NBS, hv
2) NaOEt
3) O3
4) DMS
5) excess MeMgBr
6) H2O
7) Na2Cr2O7 , H2SO4 , H2O
OH
O

e) 
1) BH3 • THF
2) H2O2 , NaOH
3) PCC, CH2Cl2
4) [H2SO4] , - H2O
CH2-
H2N
N

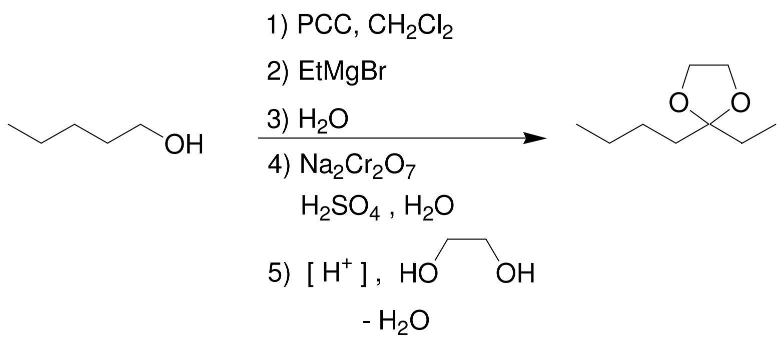
f)


1)
O
Cl
, AlCl3
2) Br2 , FeBr3
3) Ph3P=CH2
Br

g)

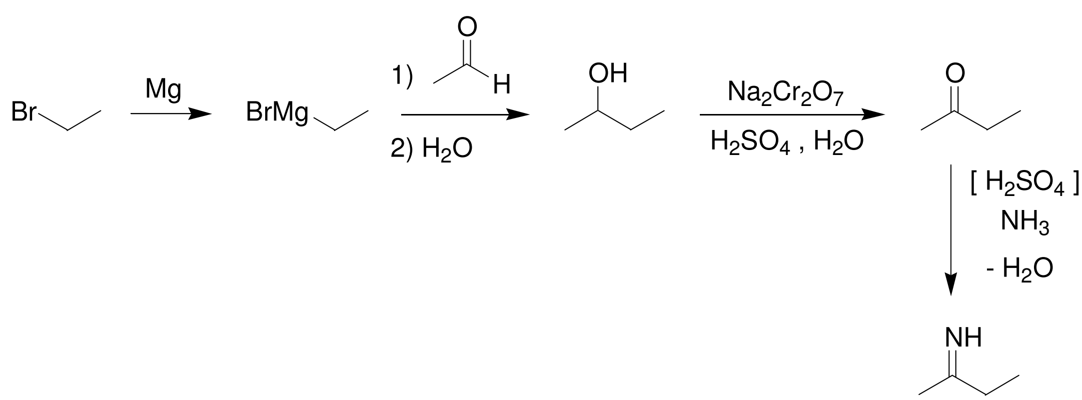

O
EtO
OEt
O
O
1) [H+] , HO OH , - H2O
2) excess LAH
3) H3O+
4) [H+] , - H2O
O O

h)

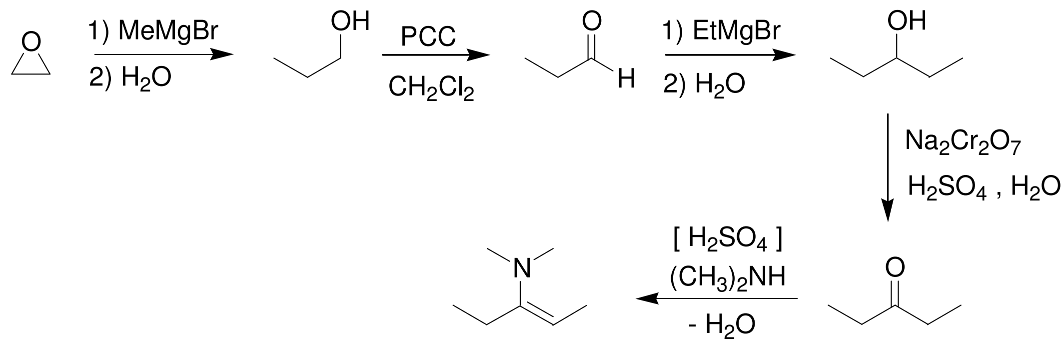

OH
1) PCC, CH2Cl2
2) EtMgBr
3) H2O
4) Na2Cr2O7
H2SO4 , H2O
5) [H+] , HO OH
- H2O
O O

20.42.

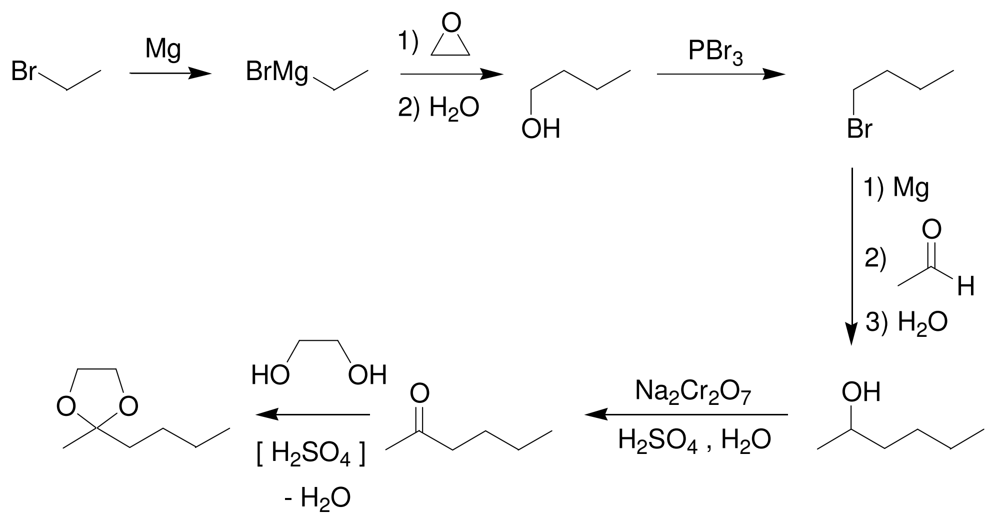
a)


Br
Mg
BrMg
1)
O
H
2) H2O
OH
Na2Cr2O7
H2SO4 , H2O
O
[H2SO4]
NH3
- H2O
NH

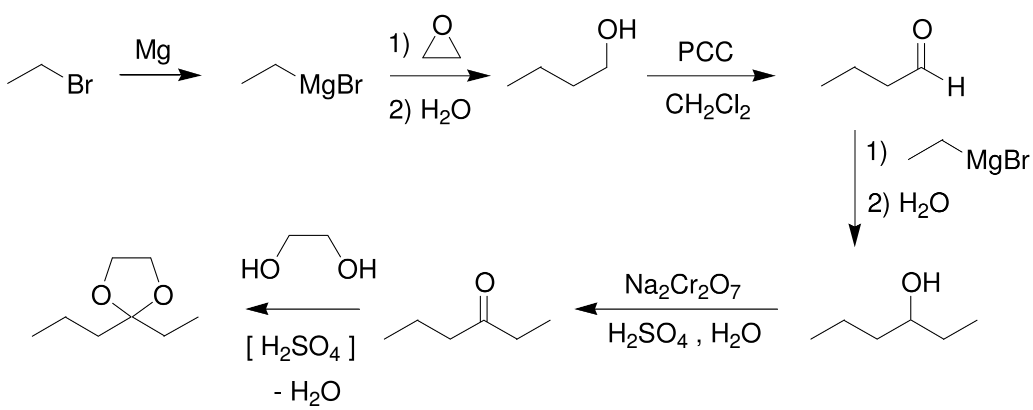
b)


O
1) MeMgBr
2) H2O
OH
PCC
CH2Cl2
O
H
1) EtMgBr
2) H2O
OH
Na2Cr2O7
H2SO4 , H2O
O
[H2SO4]
(CH3)2NH
- H2O
N

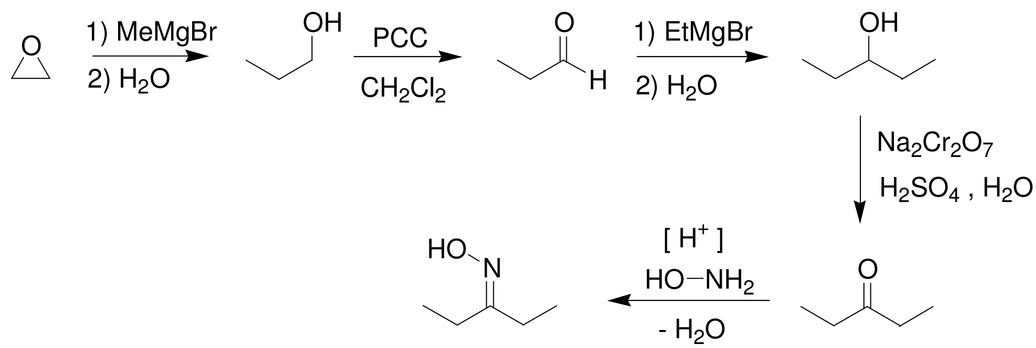
c)


Br
Mg
BrMg
1) O
2) H2O
OH
PBr3
Br
1) Mg
2) O H
3) H2O
OH
Na2Cr2O7
H2SO4 , H2O
O
HO OH
[H2SO4]
- H2O
O O

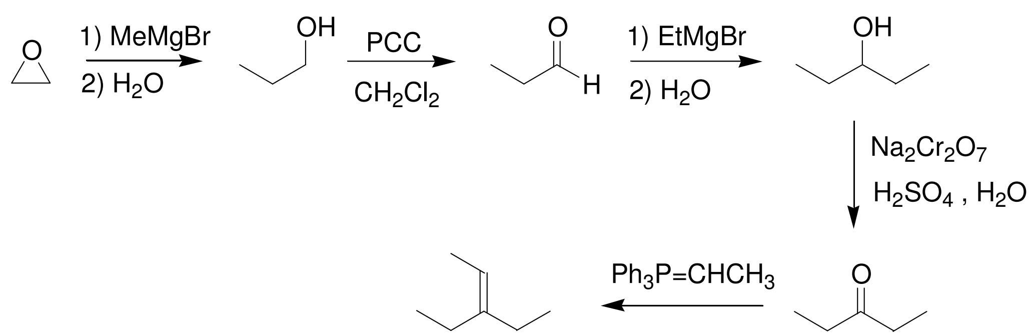
d)


Br
Mg
MgBr
1) O
2) H2O
OH
PCC
CH2Cl2
O
H
1) MgBr
2) H2O
OH
Na2Cr2O7
H2SO4 , H2O
O
HO OH
[H2SO4]
- H2O
O O

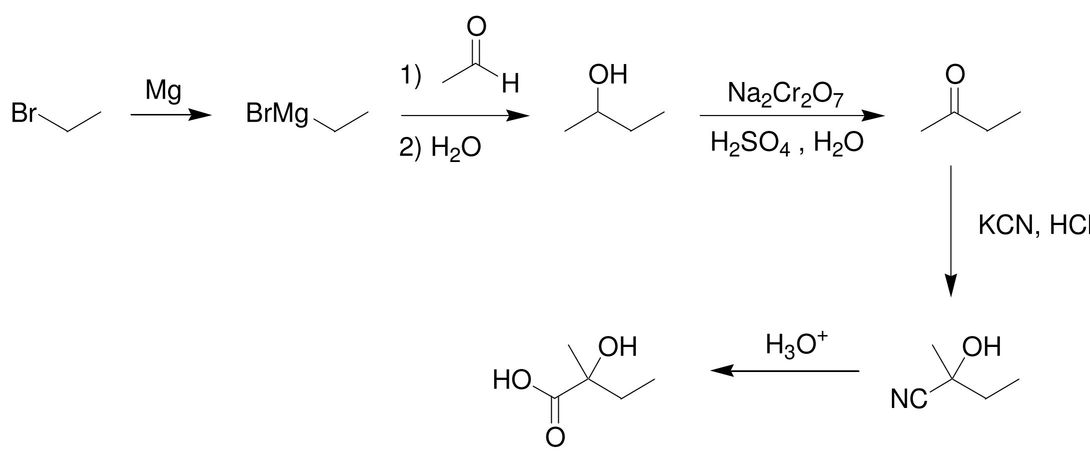
e)


O
1) MeMgBr
2) H2O
OH
PCC
CH2Cl2
O
H
1) EtMgBr
2) H2O
OH
Na2Cr2O7
H2SO4 , H2O
O
[H+]
HO−NH2
- H2O
HO
N

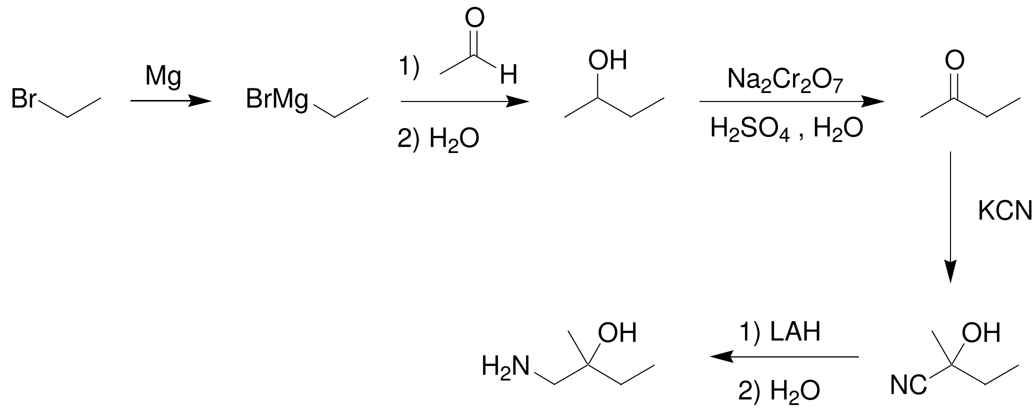
f)

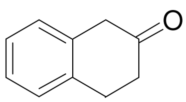

O
1) MeMgBr
2) H2O
OH
PCC
CH2Cl2
O
H
1) EtMgBr
2) H2O
OH
Na2Cr2O7
H2SO4 , H2O
O
Ph3P=CHCH3

g)

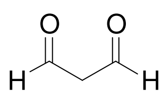
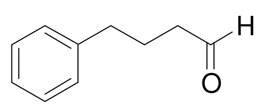
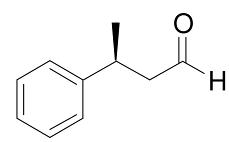

Br
Mg
BrMg
1)
O
H
2) H2O
OH
Na2Cr2O7
H2SO4 , H2O
O
KCN, HCl
OH
NC
H3O+
HO
OH
O

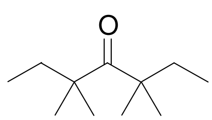
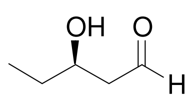
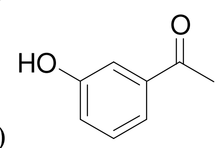
h)

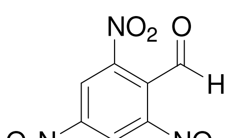
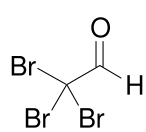
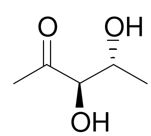


20.43.  (because this carbonyl group is not conjugated)

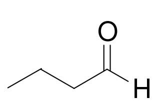
20.44. a) (*2S,3R*)-3-methyl-2-propylcyclopentanone
b) cyclohexanecarbaldehyde
c) 3-methyl-2-butenal
d) (*S*)-4-methyl-3-hexanone

20.45. a)  b)  c) 

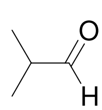
d)  e)  f) 

g)  h)  i) 

20.46.

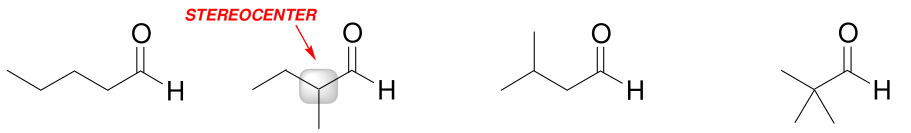


butanal



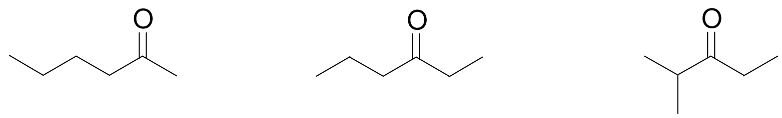
2-methylpropanal

20.47.

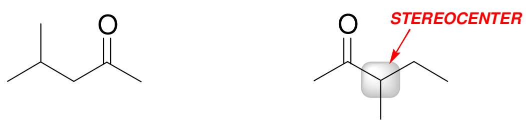


pentanal *2-methylbutanal* *3-methylbutanal* *2,2-dimethylpropanal*

20.48.

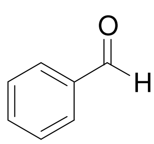


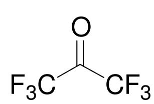
2-hexanone *3-hexanone* *2-methyl-3-pentanone*



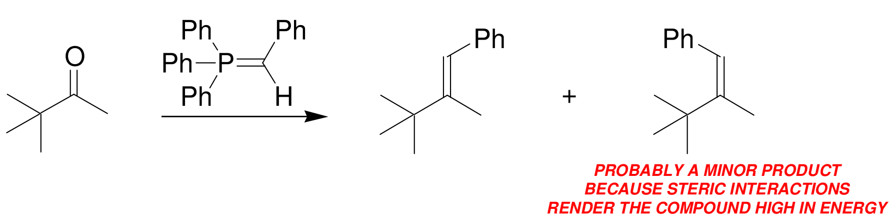
4-methyl-2-pentanone *3-methyl-2-pentanone* *3,3-dimethyl-2-butanone*

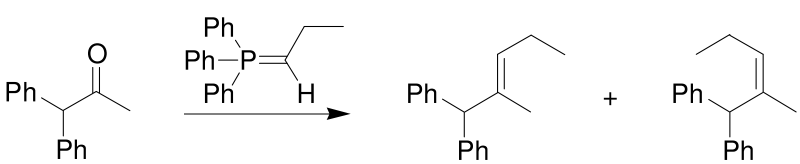
20.49. The carbonyl group of a ketone will never appear at C-1 because if it would did, the compound would be called an aldehyde rather than a ketone.

20.50. a) 

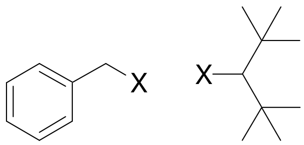
b) 

20.51

a) 

b) 

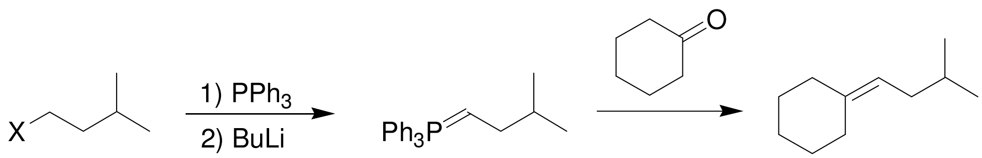
20.52.



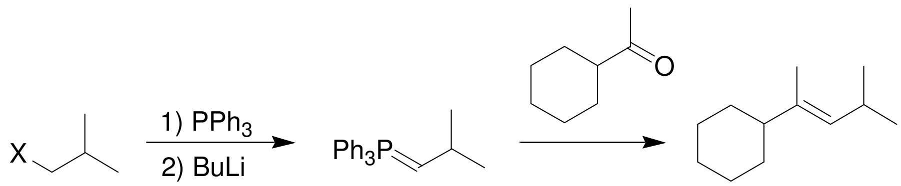
The latter alkyl halide above will be more difficult to convert into a Wittig reagent, because it is too sterically hindered to undergo S_N2 attack.

20.53.

a)

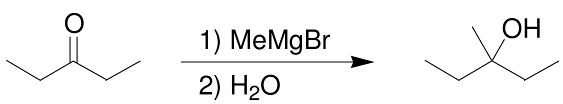


b)

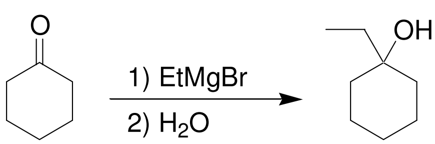


20.54.

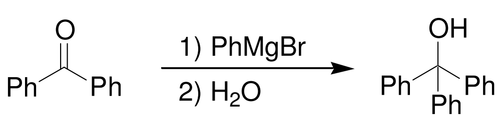
a)



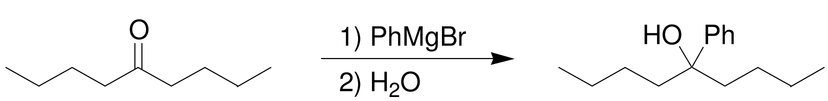
b)



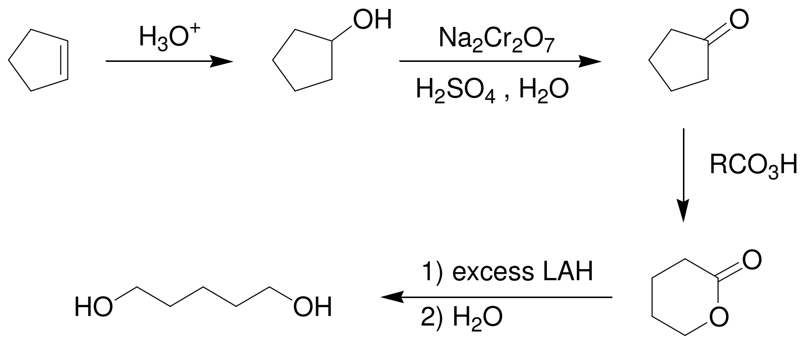
c)



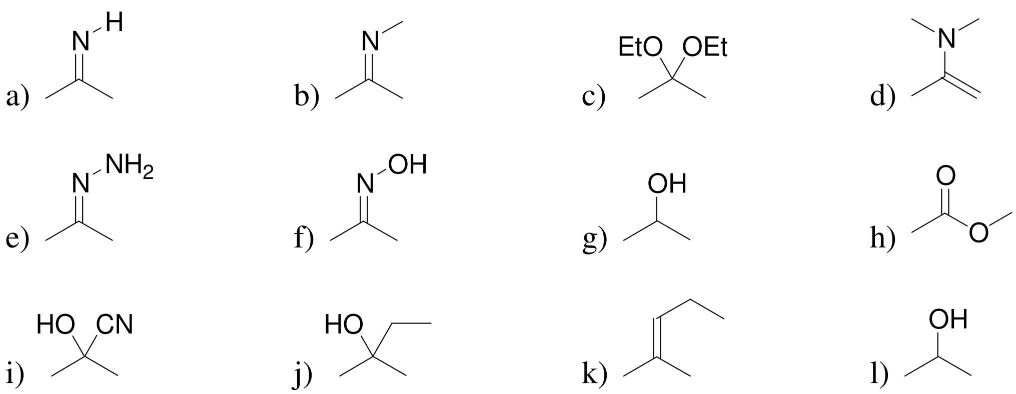
d)



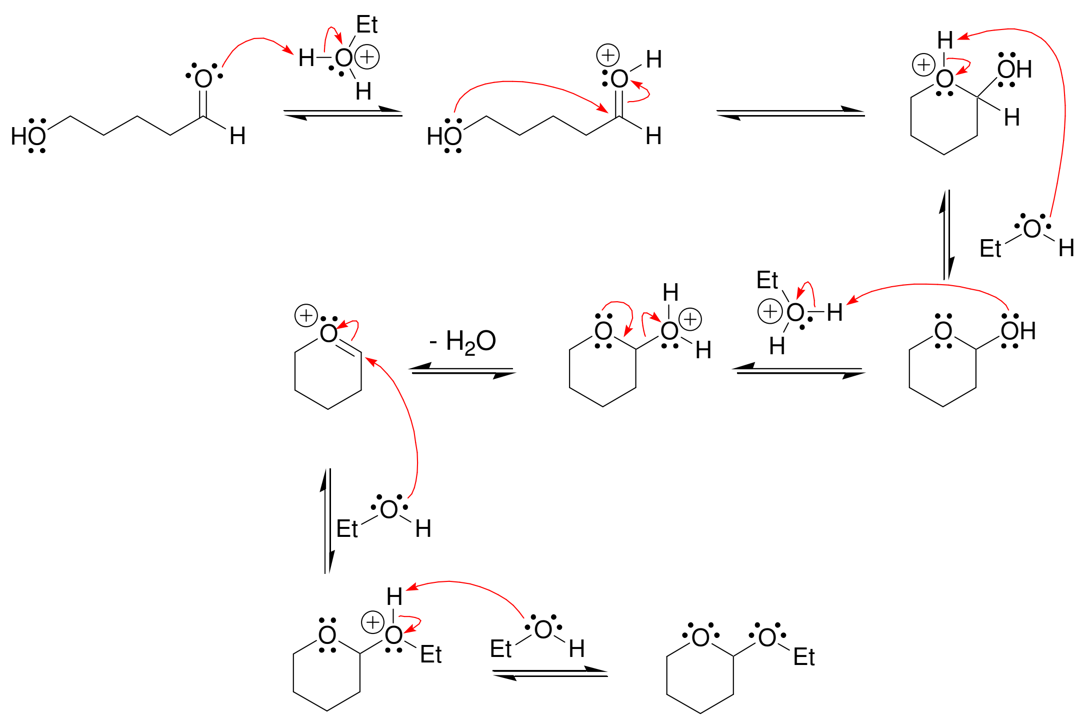
20.55.



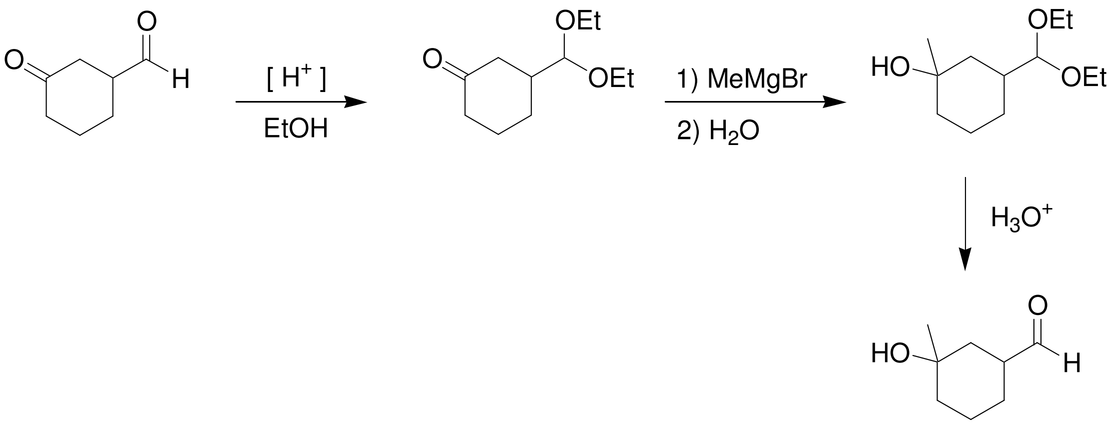
20.56.



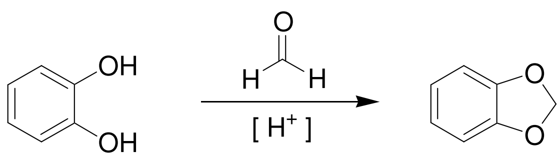
20.57.



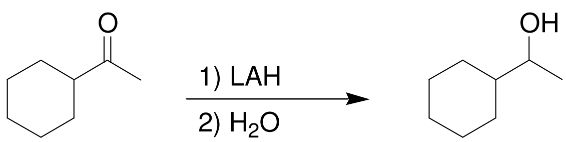
20.58.



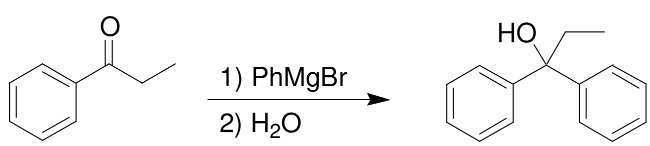
20.59.



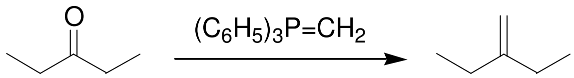
20.60. a)



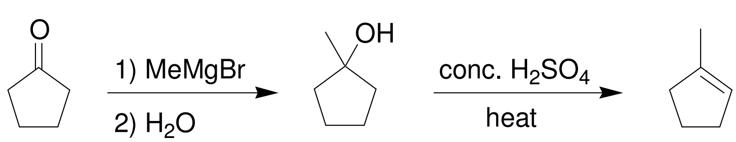
b)



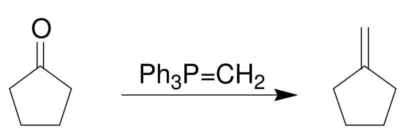
c)



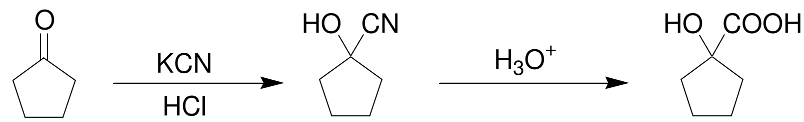
20.61. a)



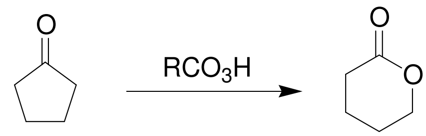
b)



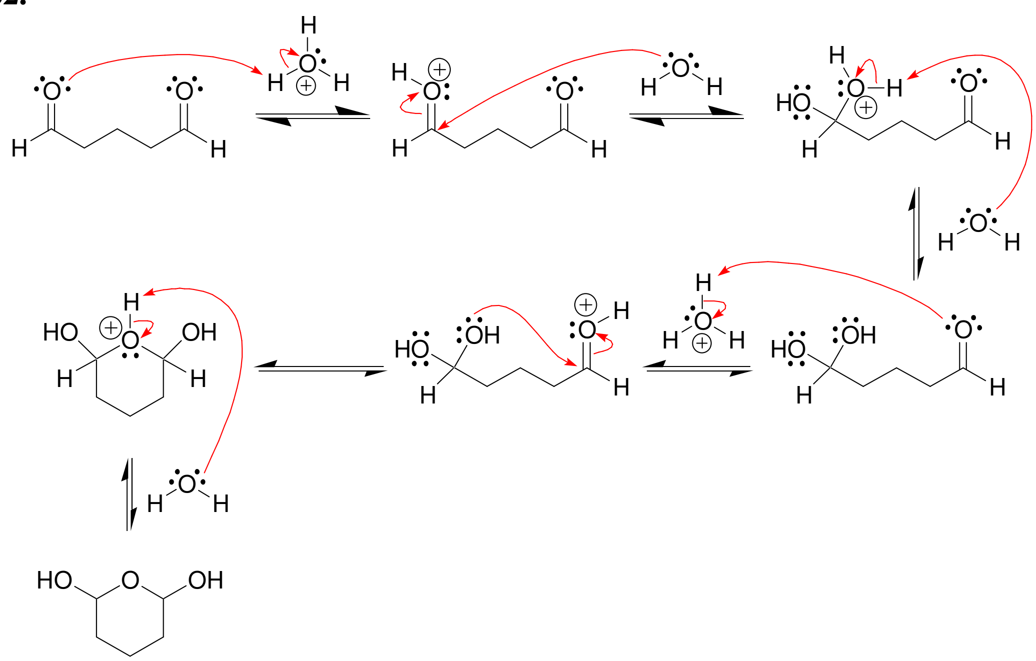
c)



d)

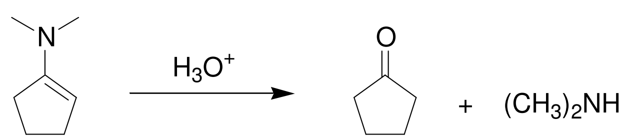


20.62.

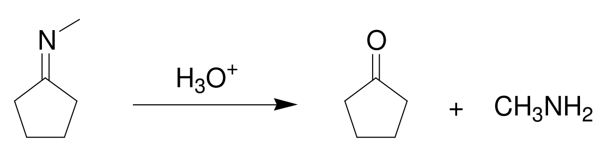


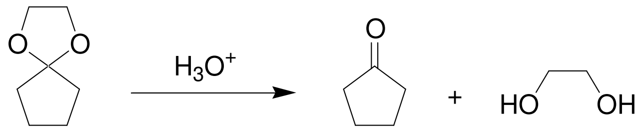
20.63.

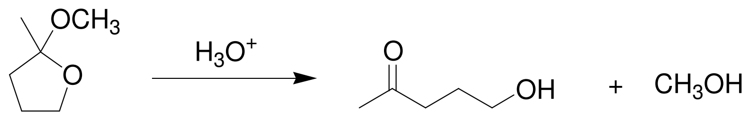
a)



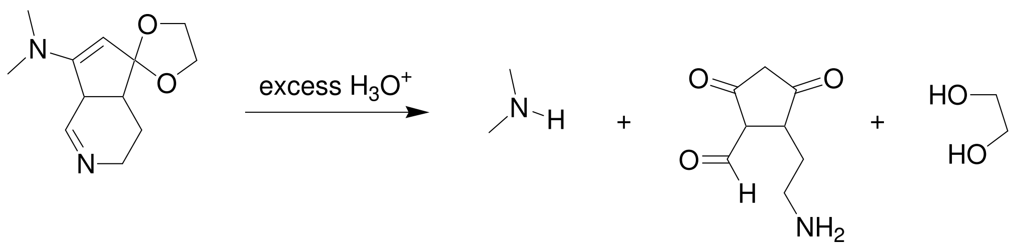
b)



c) 

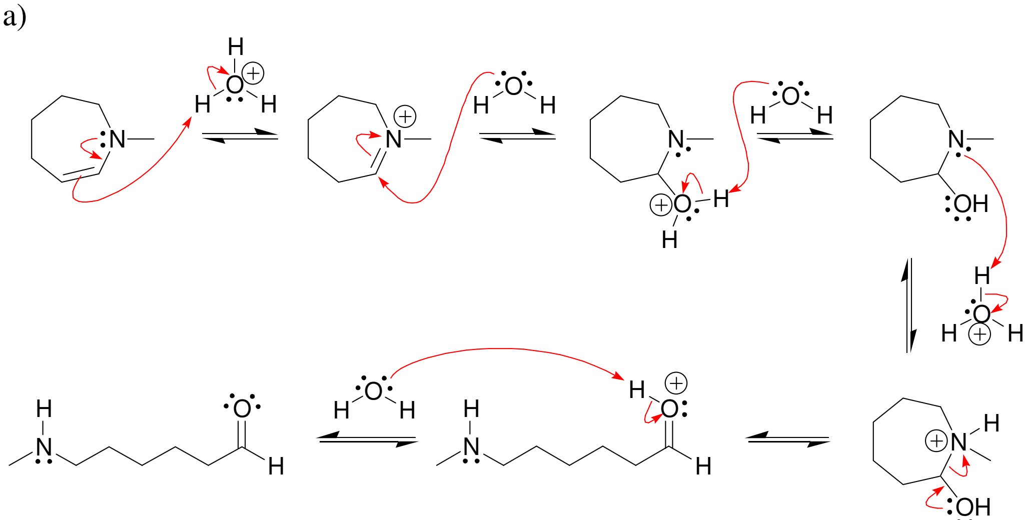
d) 

20.64.

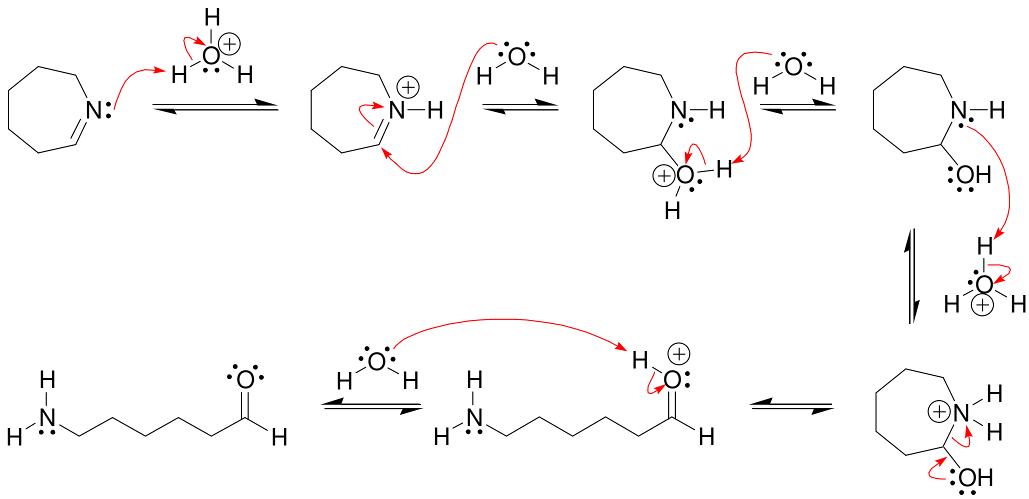


20.65.

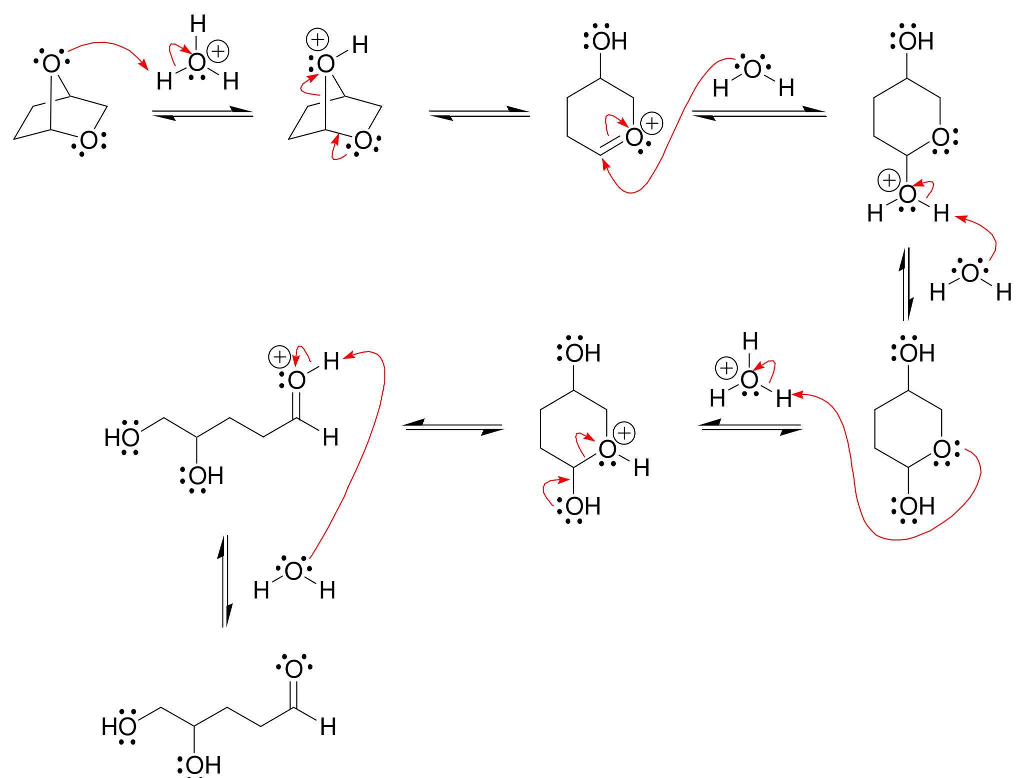
a)



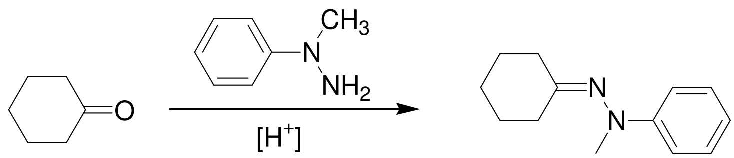
b)

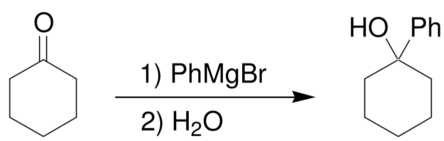


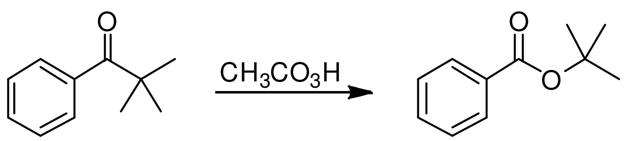
c)

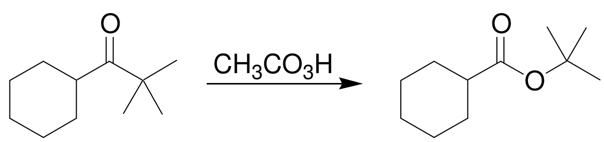


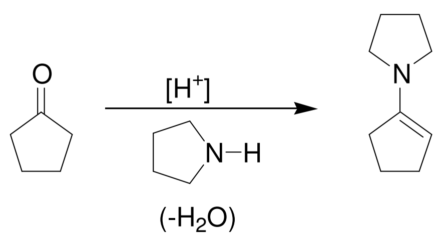
20.66.

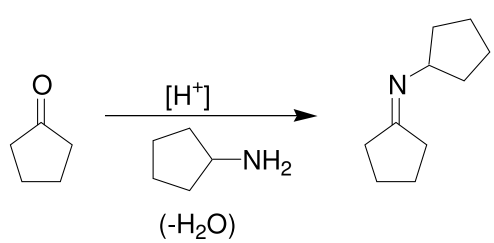
a) 

b) 

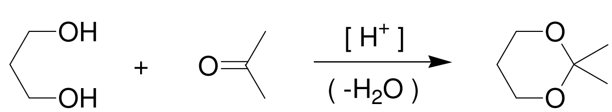
c) 

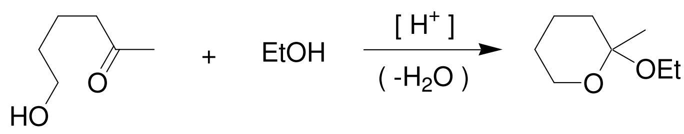
d) 

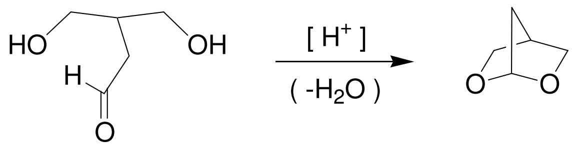
e) 

f) 

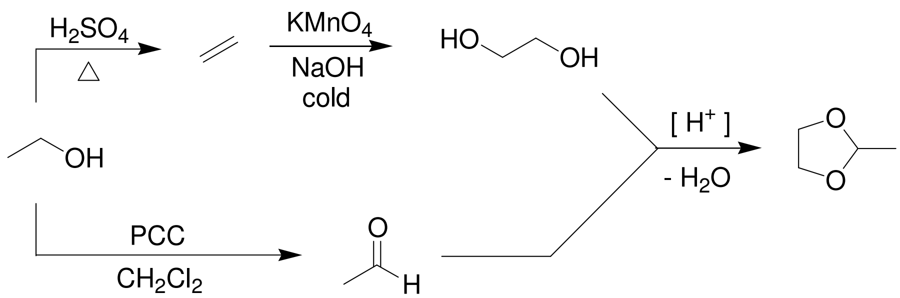
20.67.

a) 

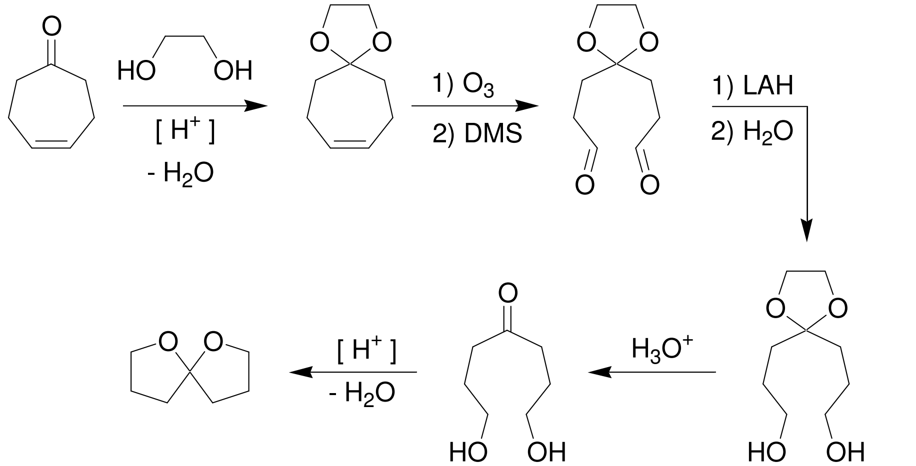
b) 

c) 

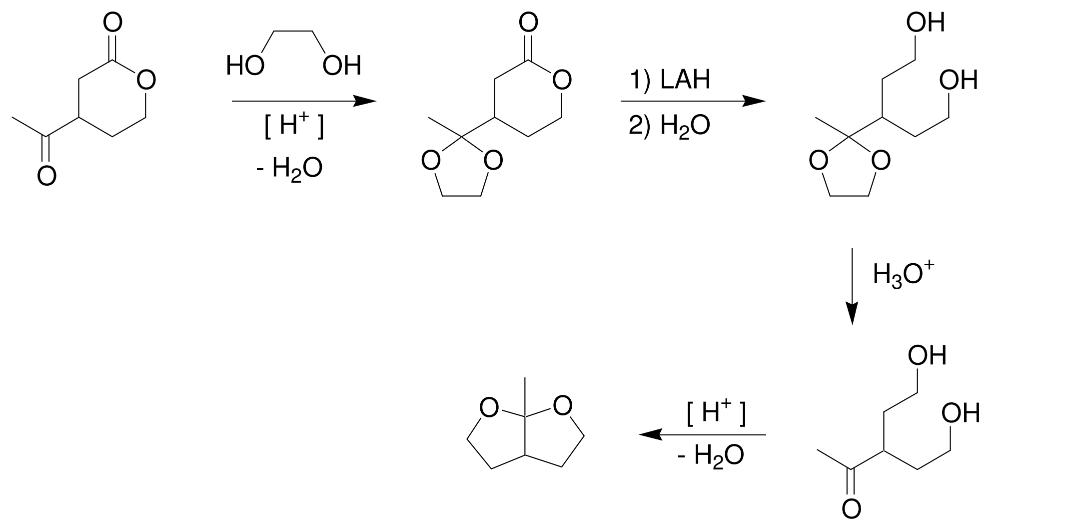
20.68.



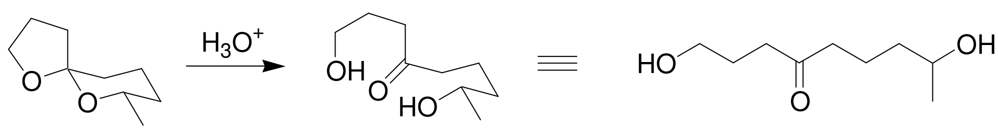
20.69.

a) 

b)

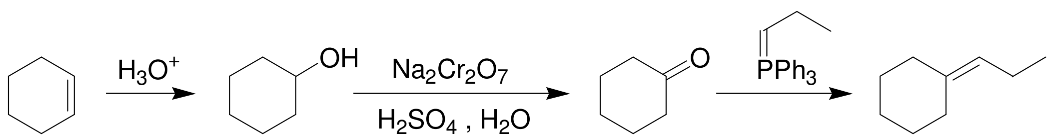


20.70.



20.71.

a)



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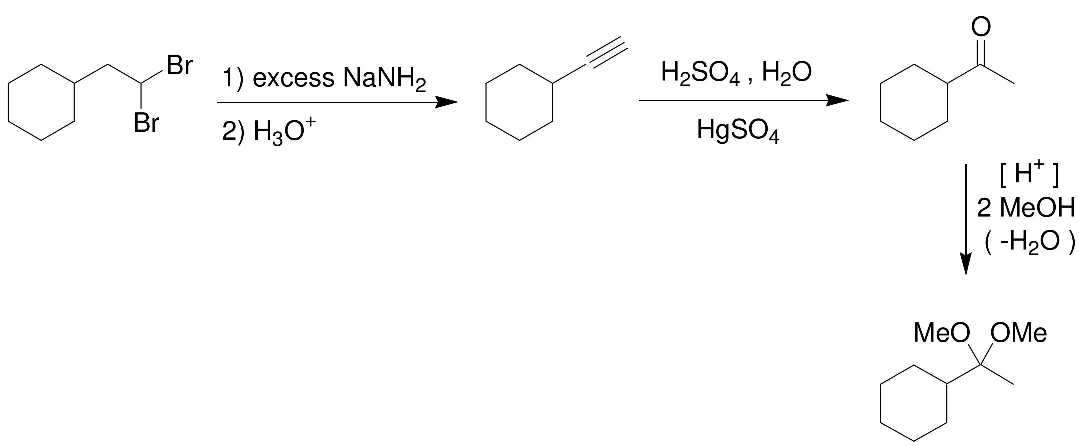

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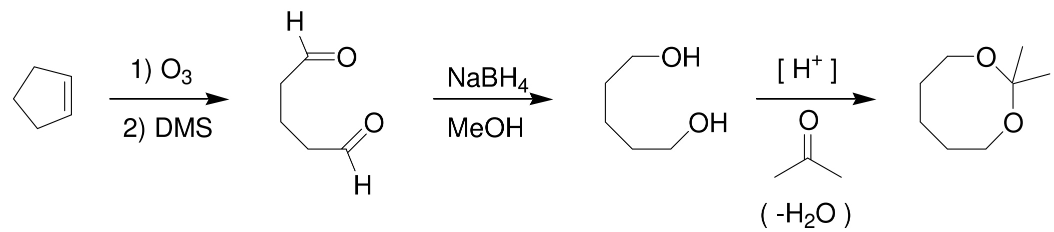
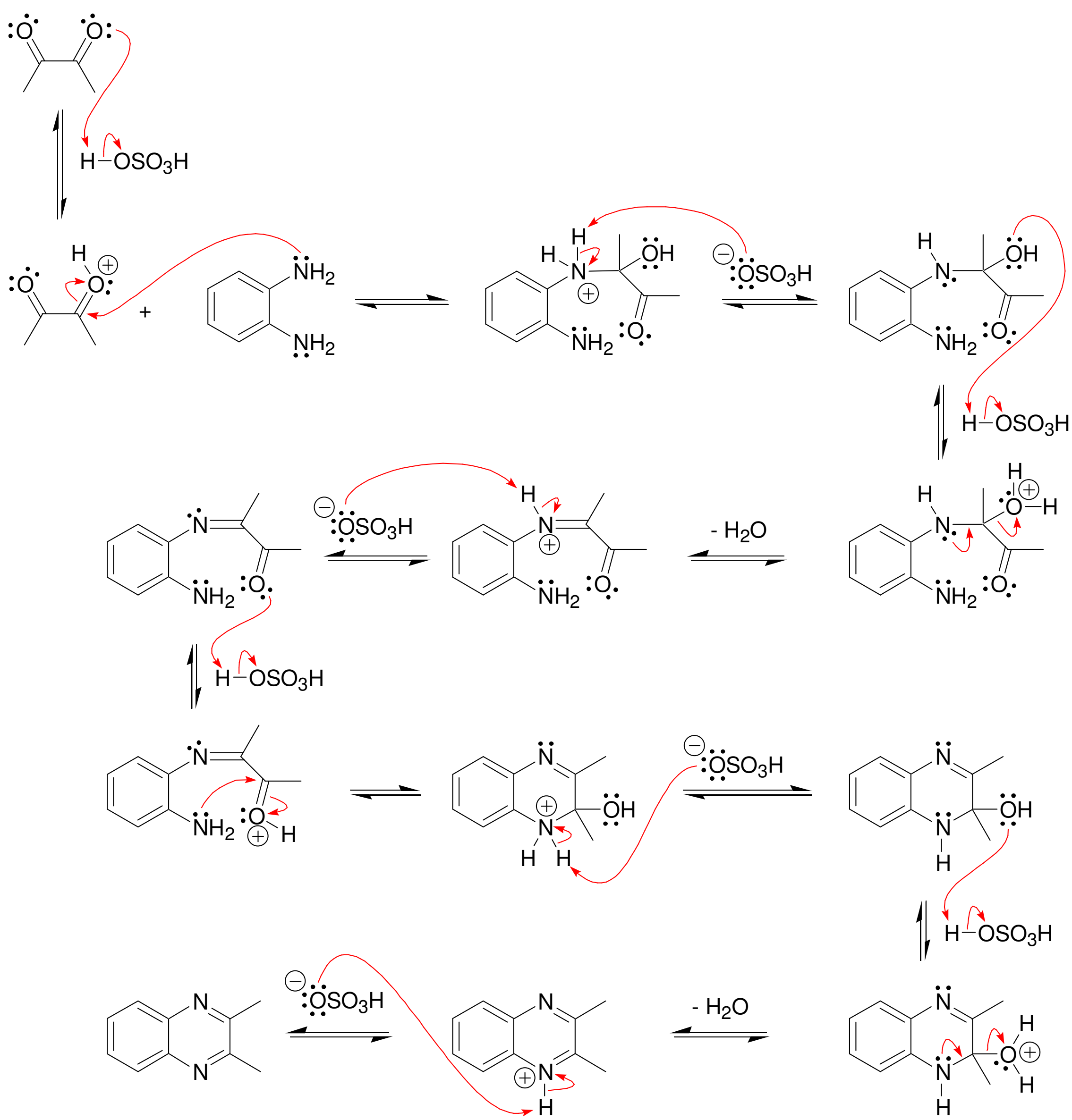

1) O3
2) DMS
H
O
O
H
NaBH4
MeOH
OH
OH
[H+]
O
(-H2O)
O
O

20.72.

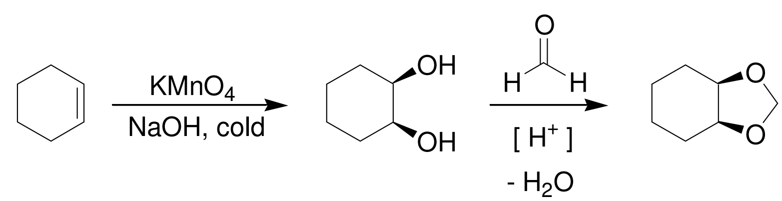

H–OSO3H
NH2
NH2
+
OSO3H
- H2O
OH
N
H

20.73. Cyclopropanone exhibits significant ring strain, with bond angles of approximately 60º. Some of this ring strain is relieved upon conversion to the hydrate, because an *sp*^{2}-hybridized carbon atom (that must be 120º to be strain free) is replaced by an *sp*^{3}-hybridized carbon atom (that must be only 109.5º to be strain free). In contrast, cyclohexanone is a larger ring and exhibits only minimal ring strain. Conversion of cyclohexanone to its corresponding hydrate does not alleviate a significant amount of ring strain.

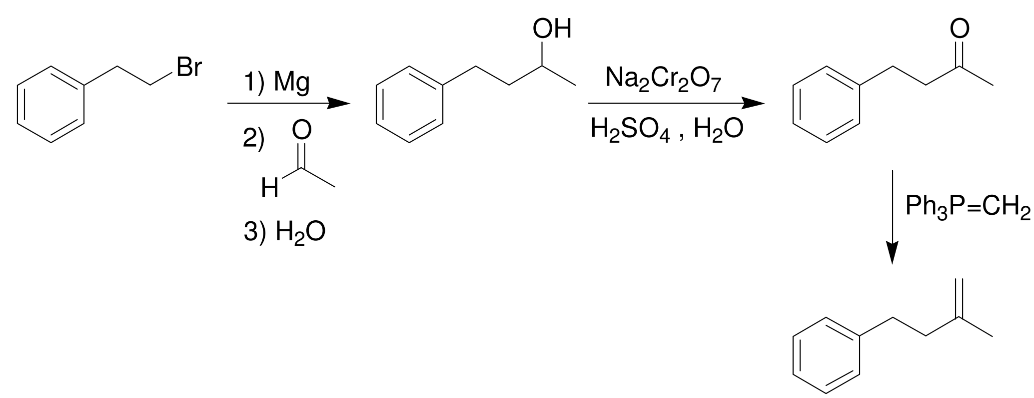
20.74. 1,2-dioxane has two adjacent oxygen atoms and is therefore a peroxide. Like other peroxides, it is extremely unstable and potentially explosive.
1,3-dioxane has two oxygen atoms separated by one carbon atom. This compound is therefore an acetal. Like other acetals, it is only stable under basic conditions, but undergoes hydrolysis under mildly acidic conditions.
1,4-dioxane is stable under basic conditions as well as mildly acidic conditions, and is therefore used as a common solvent.

20.75.

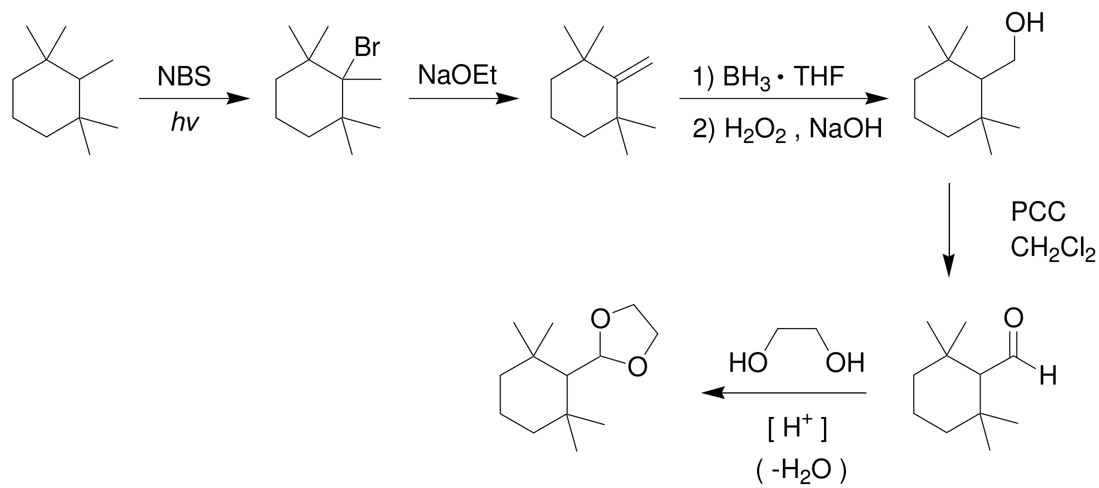
a)



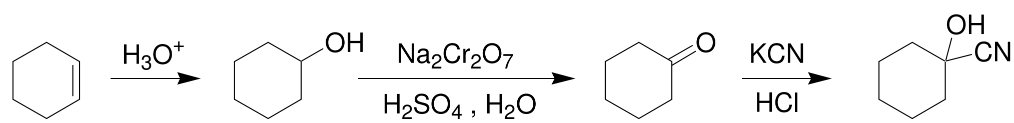
b)



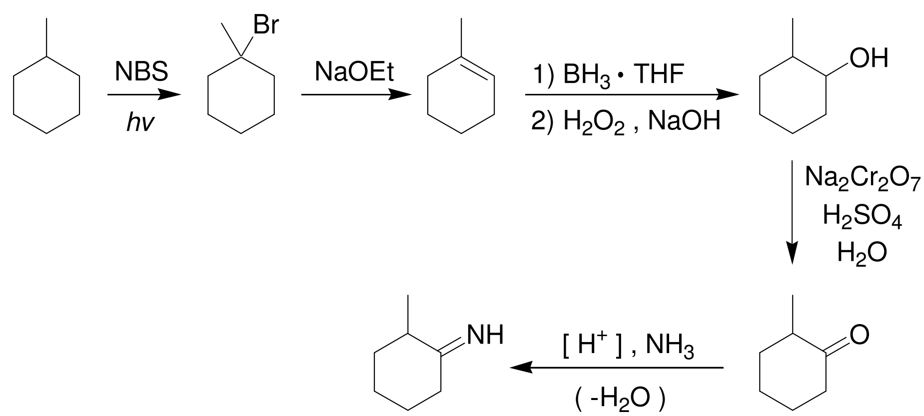
c)


NBS
hv
Br
NaOEt
1) BH3 • THF
2) H2O2 , NaOH
OH
PCC
CH2Cl2
O
H
HO
OH
[H+]
(-H2O)
O
O

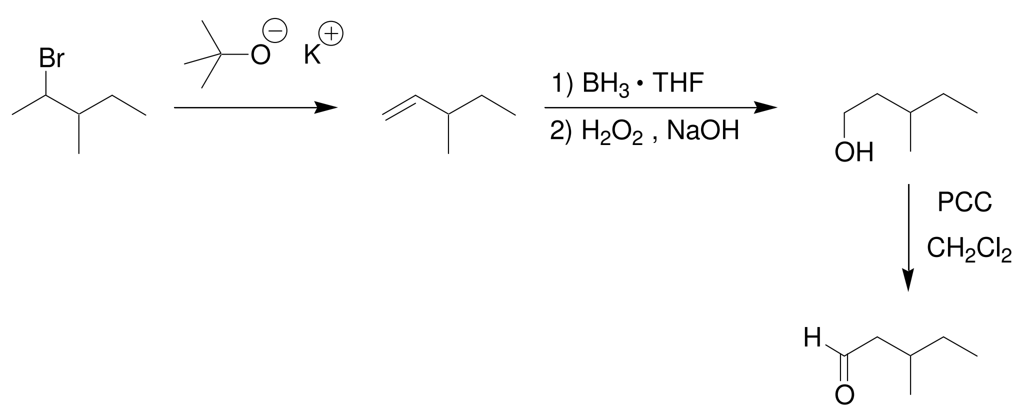
d)


H3O+
OH
Na2Cr2O7
H2SO4 , H2O
O
KCN
HCl
OH
CN

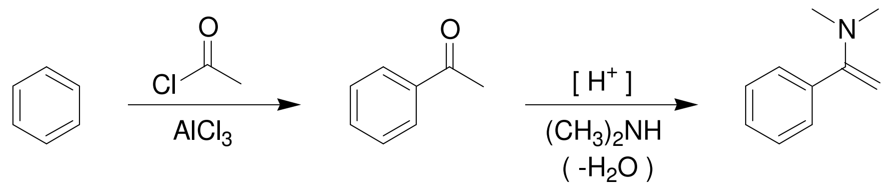
e)


NBS
hv
Br
NaOEt
1) BH3 • THF
2) H2O2 , NaOH
OH
Na2Cr2O7
H2SO4
H2O
O
[H+] , NH3
(-H2O)
NH

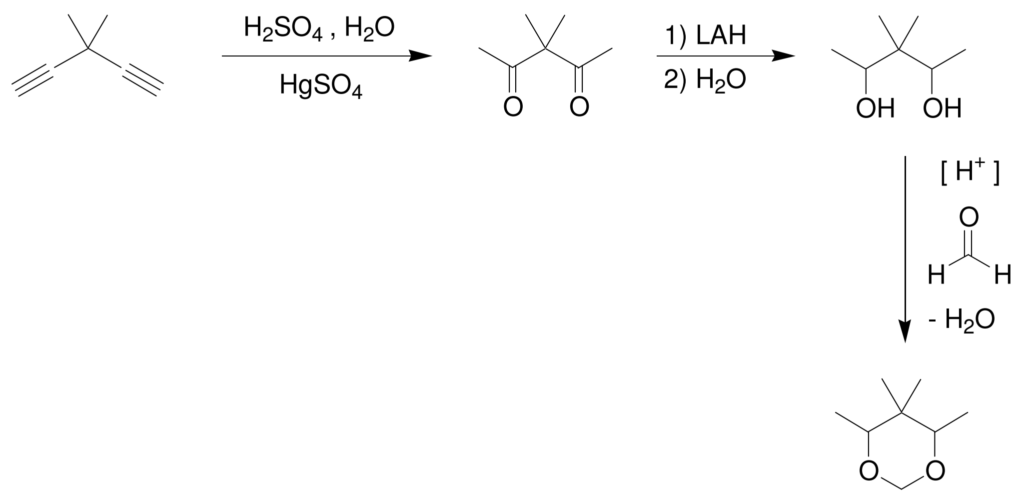
f)


Br
O
K
1) BH3 • THF
2) H2O2 , NaOH
OH
PCC
CH2Cl2
H
O

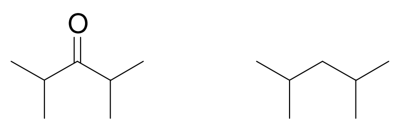
g)



h)



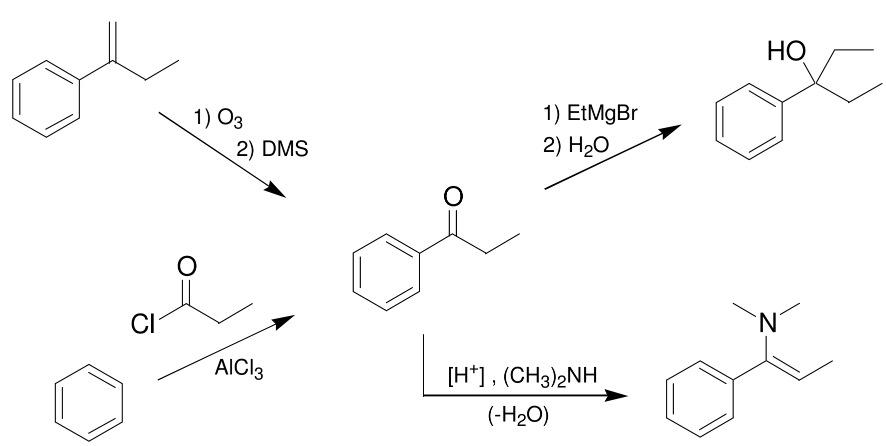
20.76.



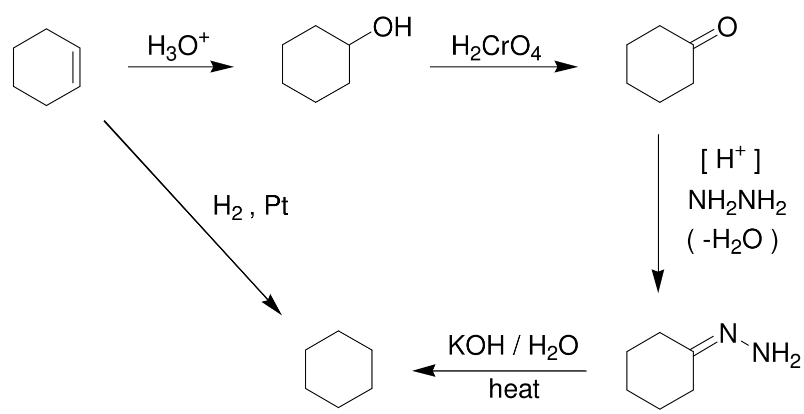
Compound A ***Compound B***

a) Three
b) Three
c) Compound A is a ketone, while Compound B is an alkane. Therefore, Compound A will exhibit a signal at approximately 1715 cm^{-1}, while Compound B will not exhibit a signal in the same region.

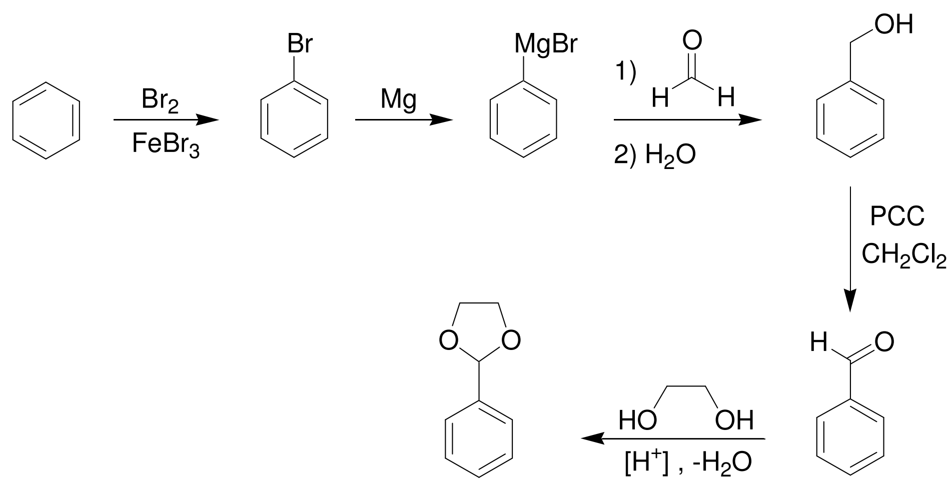
20.77.



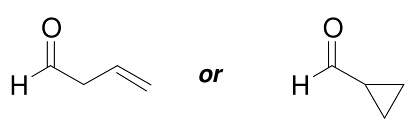
20.78.



20.79.

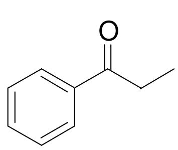


20.80. a)

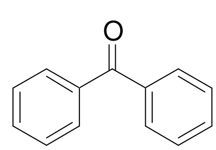


b) The first compound above would exhibit four signals in its ^{13}C NMR spectrum, while the second compound would exhibit only three signals in its ^{13}C NMR spectrum.

20.81.



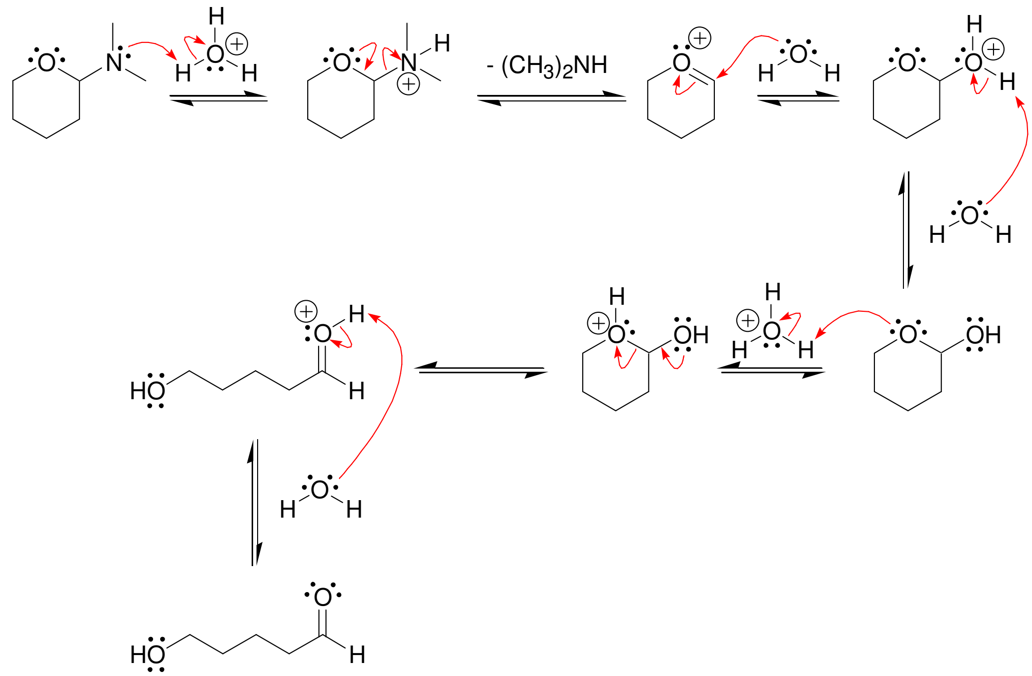
20.82.



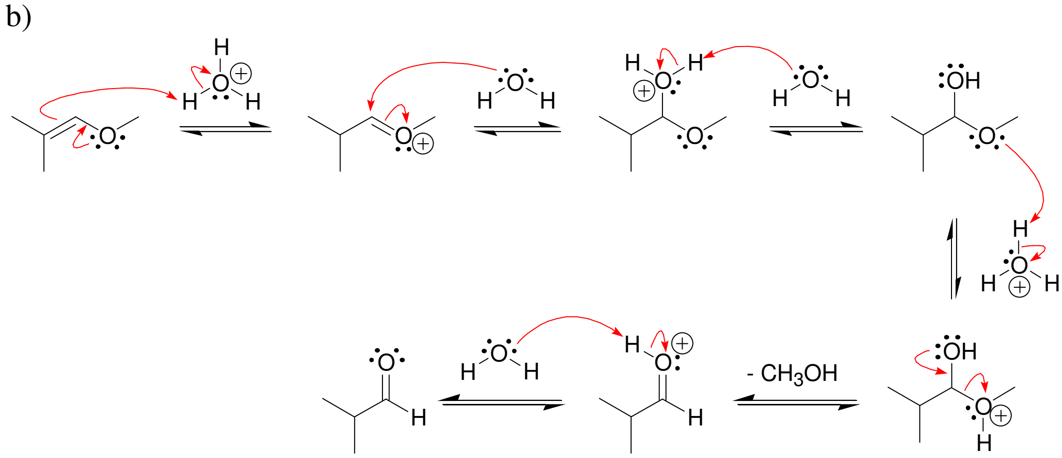
20.83. 2,2,4,4-Tetramethyl-3-pentanone

20.84.

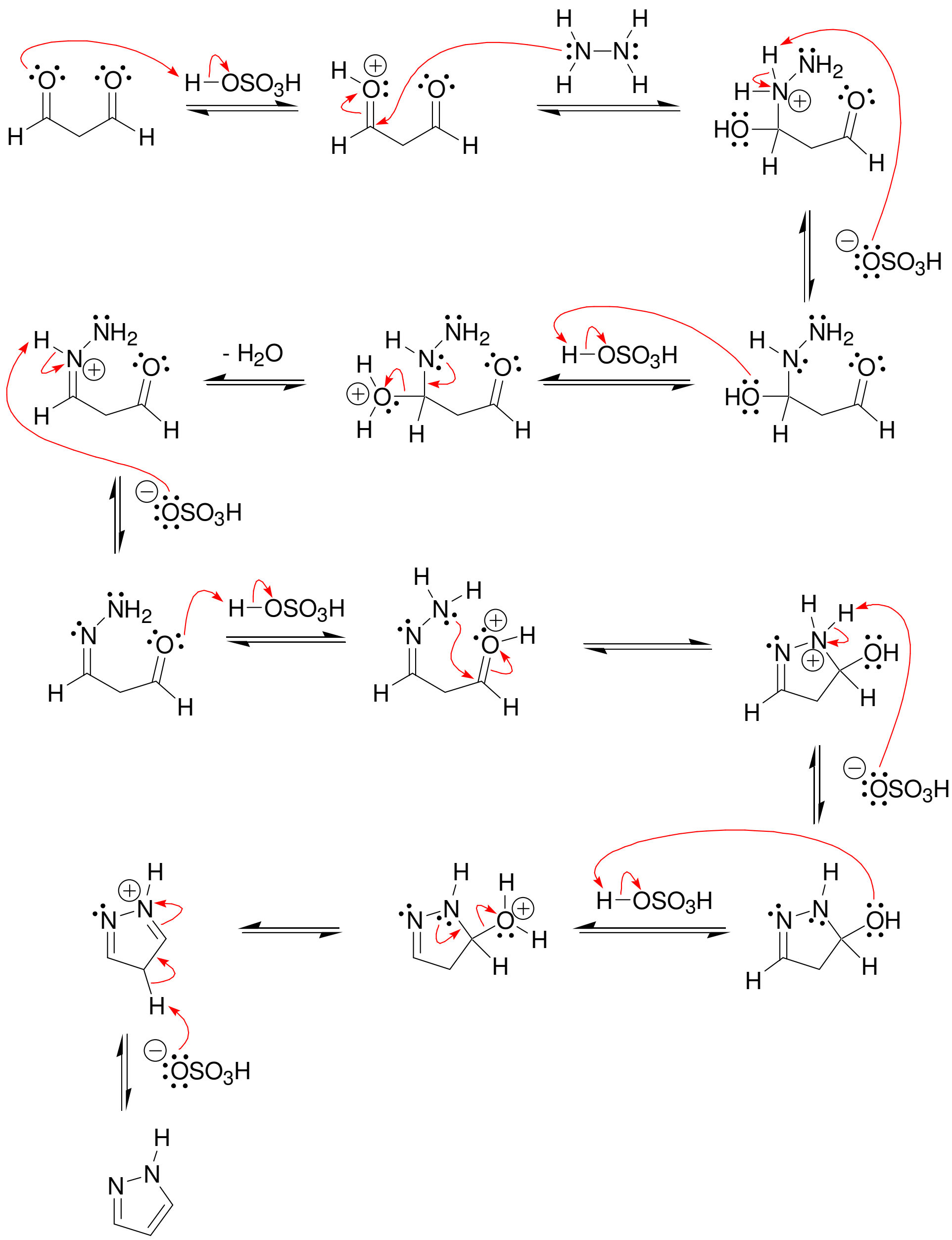
a)



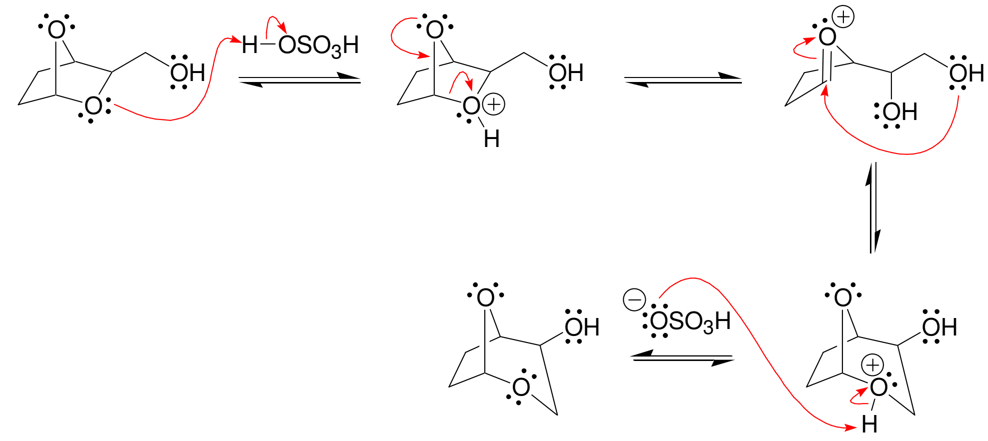
b)



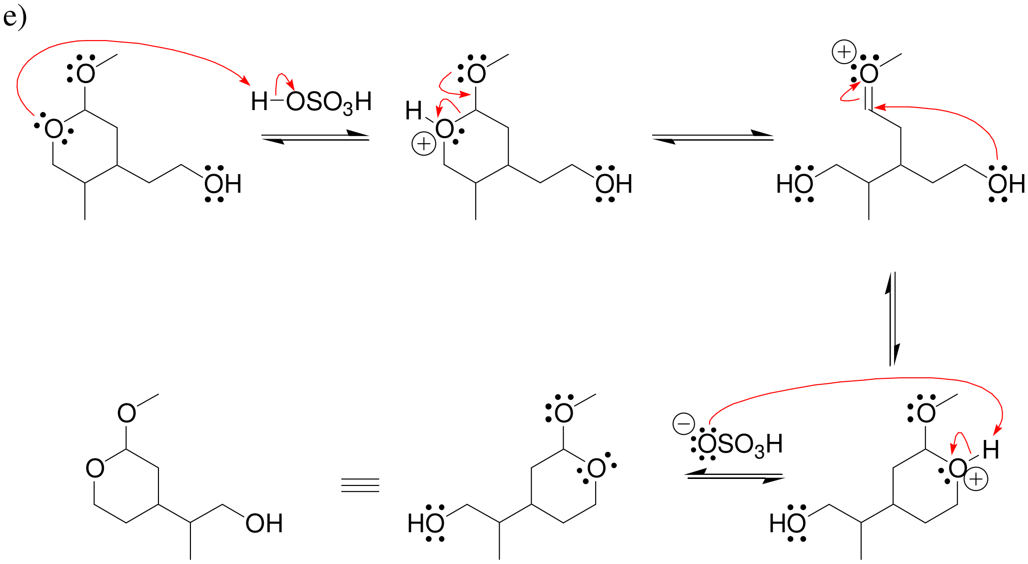
c) **Note**: ***The first two steps of the mechanism below can be reversed (first the amine attacks the carbonyl group, and then the tetrahedral intermediate is protonated). The same is true for attack of the second carbonyl group (half-way through the mechanism). It would be wise to check your lecture notes to determine if you instructor has a strong preference for this alternate sequence of steps.***



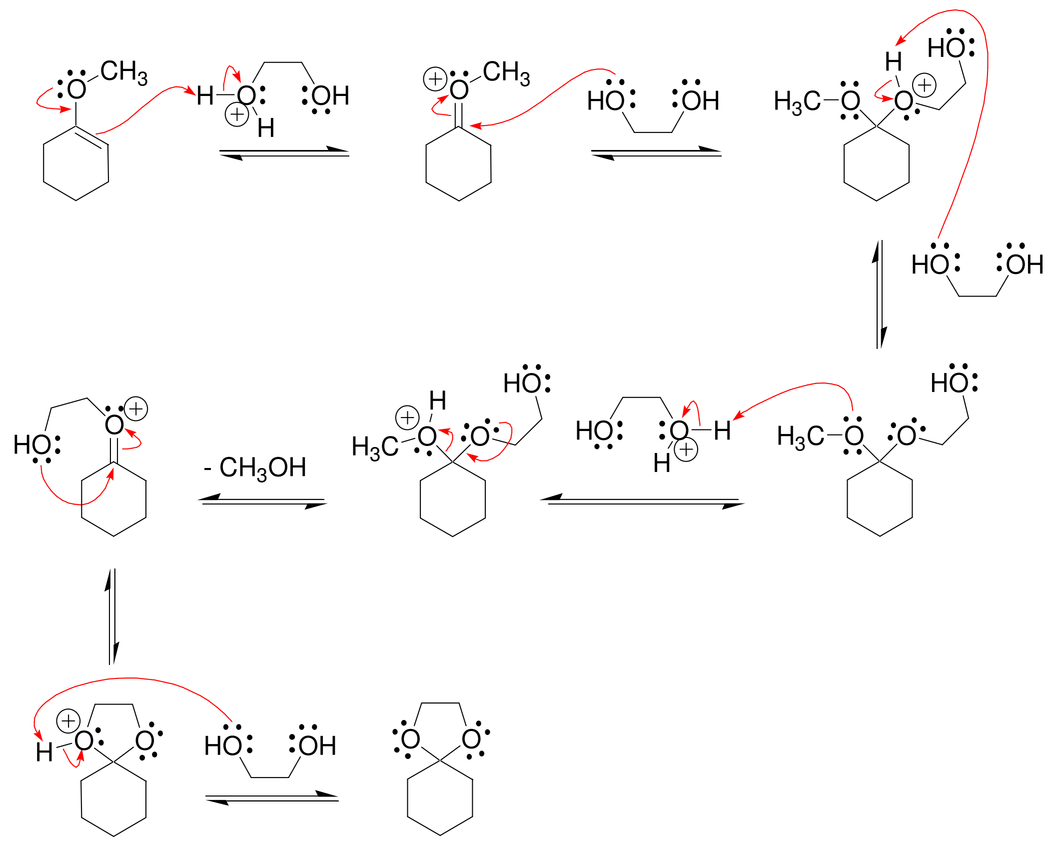
d)



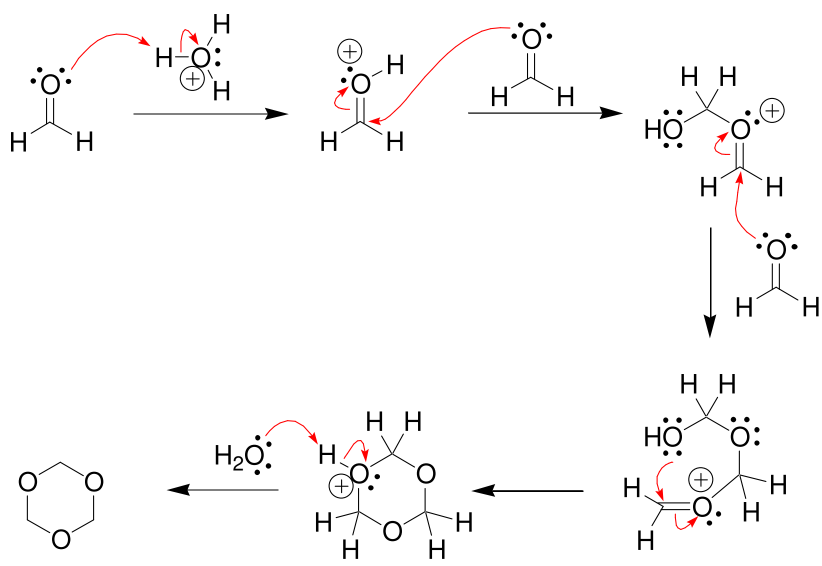
e)



f)



20.85.



paraformaldehyde