NAME (Print): _____

EID _____

SIGNATURE: _____

Chemistry 320N
Final Exam
May 2, 2026

Please print the first three letters of your last name in the three boxes

Please Note: Please take your time. You have three hours to take this exam. Please do not rush, we want you to show us everything you have learned during your organic chemistry journey. Making careless mistakes is not good for anyone! If you find yourself getting anxious because of a problem, skip it and come back. Please do not second guess yourself! Keep track of the questions worth a lot of points. (This does not mean they are hard, it just means we think they cover important material.)

One last thing: I recommend you close your eyes for a moment, then take some nice deep breaths before you begin. YOU GOT THIS!

FINALLY, DUE TO SOME UNFORTUNATE RECENT INCIDENTS YOU ARE NOT ALLOWED TO INTERACT WITH YOUR SMART WATCH OR CELL PHONE IN ANY WAY. IF YOU TOUCH YOUR SMART WATCH OR CELL PHONE DURING THE EXAM YOU WILL GET A "0" NO MATTER WHAT YOU ARE DOING WITH THE SMART WATCH OR PHONE. PUT THEM AWAY AND LEAVE THEM THERE!!!

Student Honor Code for the University of Texas at Austin

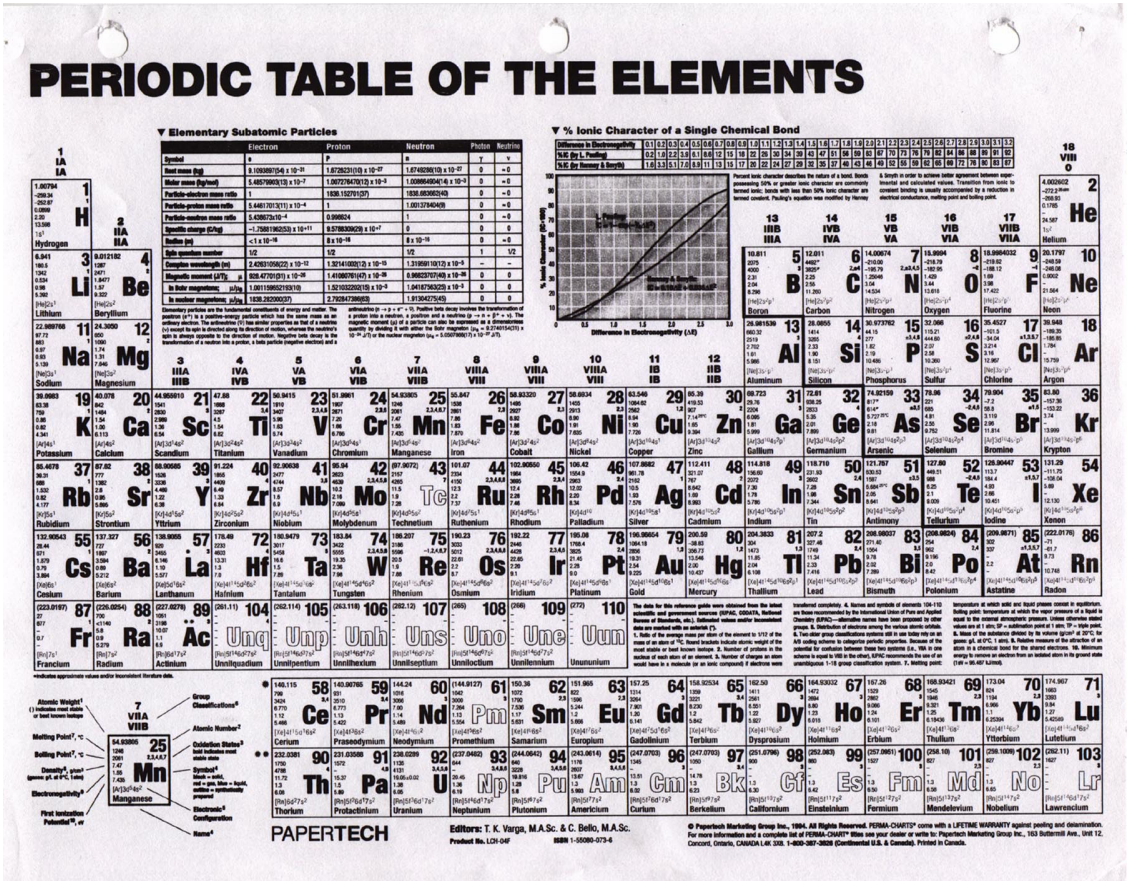
"I pledge, as a member of The University of Texas at Austin community, to do my work honestly, respectfully, and through the intentional pursuit of learning and scholarship."

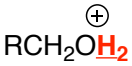
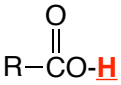
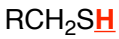
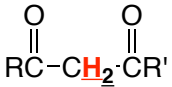
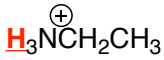
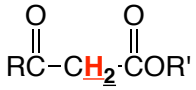
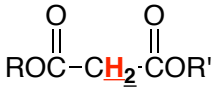
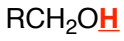
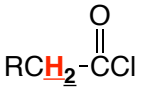
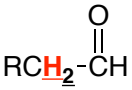
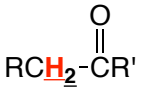
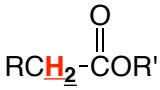
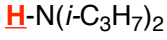
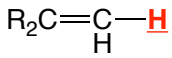
Elaboration

1. I pledge to be honest about what I create and to acknowledge what I use that belongs to others.
2. I pledge to value the process of learning in addition to the outcome, while celebrating and learning from mistakes.
3. This code encompasses all of the academic and scholarly endeavors of the university community.

_____

(Your signature)



Compound		pK_a
Hydrochloric acid		-7
Protonated alcohol		-2
Hydronium ion		-1.7
Carboxylic acids		3-5
Thiols		8-9
Ammonium ion		9.2
β-Dicarbonyls		10
Primary ammonium		10.5
β-Ketoesters		11
β-Diesters		13
Water		15.7
Alcohols		15-19
Acid chlorides		16
Aldehydes		18-20
Ketones		18-20
Esters		23-25
Terminal alkynes		25
LDA		40
Terminal alkenes		44
Alkanes		51

Golden Rules of Chemistry for your reference

A. Predicting Structure and Bonding 1. In most stable molecules, all the atoms will have filled valence shells. 2. Five- and six-membered rings are the most stable. 3. There are two possible arrangements of four different groups around a tetrahedral atom.
B. Predicting Stability and Properties 4. The most important question in organic chemistry is "Where are the electrons?" 5. Delocalization of charge over a larger area is stabilizing. 6. Delocalization of unpaired electron density over a larger area is stabilizing. 7. Delocalization of pi electron density over a larger area is stabilizing. **C. Predicting Reactions** 8. Reactions will occur if the products are more stable than the reactants and the energy barrier is low enough. 9. Functional groups react the same in different molecules. 10. A reaction mechanism describes the sequence of steps occurring during a reaction. 11. Most bond-making steps in reaction mechanisms involve nucleophiles reacting with electrophiles.

This has been quite a year. A lot has happened on the 40 acres and beyond these past months. And I have to say, at the beginning of the semester, I was concerned. The average scores on the first exam were not where I wanted and I struggled to find a way to connect with many of you. But I kept trying, and more importantly, all of YOU kept trying. And soon we were able to find more common ground and I saw the improvement. There is always room for more, but I believe many of you have successfully caught the OChem II wave. I am proud of you and it has been an honor to be on this part of your journeys with you.

And if you have gone through my previous finals you have seen this poem before, but I want you to read this on your own OChem II final exam. This is to each one of you, my sincere wish, taken from the words of one of the great poets of the 20th Century, Bob Dylan.

"May your wishes all come true
May you always do for others
And let others do for you
May you build a ladder to the stars
And climb on every rung
May you stay forever young

May you always know the truth
And see the light surrounding you
May you always be courageous
Stand upright and be strong
May you stay forever young

May your hands always be busy
May your feet always be swift
May you have a strong foundation
When the winds of changes shift
May your heart always be joyful
May your song always be sung
And may you stay forever young"

Here is my original final verse, written specifically for each of you:

"Every chance you get,
You should go out for a run,
That is the very best way
For you to stay forever young."

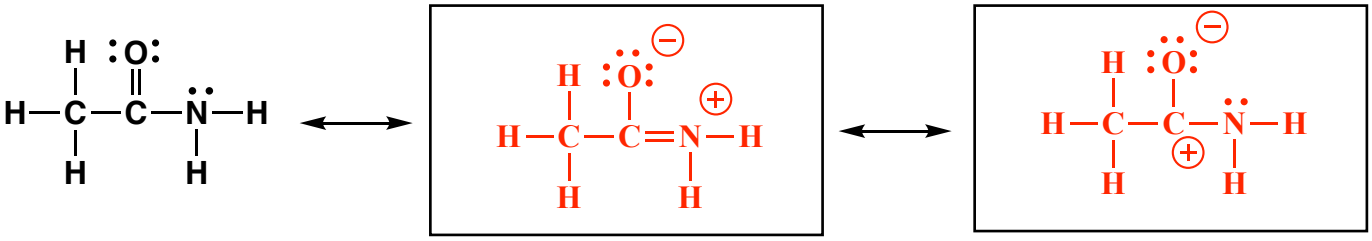
DON'T TEAR OUT THIS PAGE, *IT WILL MESS UP OUR SCANS!!!*

Use this for scratch paper

1. (5 pts) What is the most important question in organic chemistry?

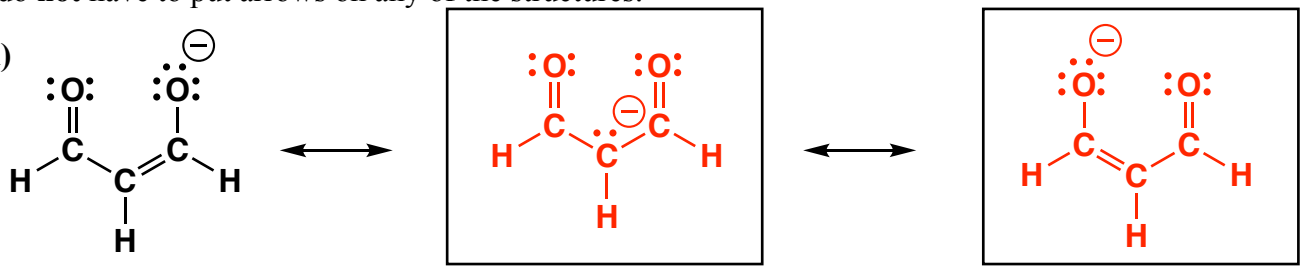
Where are the electrons?

2. (10 pts) Amides are best represented as the hybrid of three contributing structures. Draw the second and third important contributing structures in the spaces provided. You do **not** have to put arrows on any of the structures.

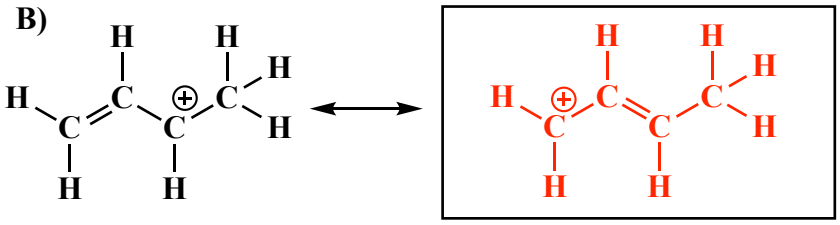


3. (20 pts) Many other molecules you have seen are best represented as the hybrid of contributing structures. Draw the most important contributing structures for each species in the spaces provided. You do **not** have to put arrows on any of the structures.

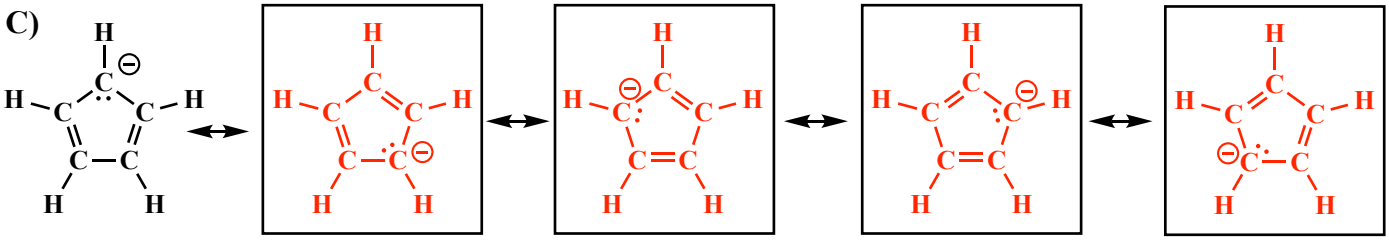
A)



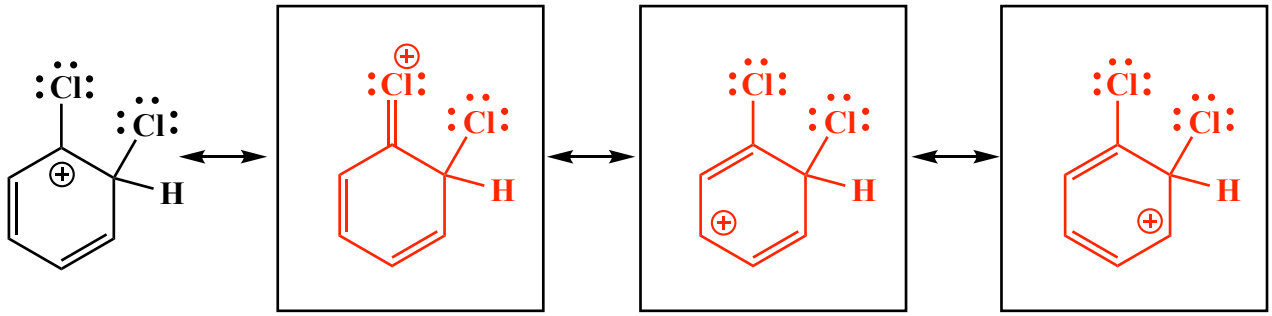
B)



C)



D)



4. (2 pts each). Here is an OChem II Crossword puzzle! Fill in the word that is missing in each clue and write it in the appropriate boxes on Page 3. You will likely recognize these as Rules of the Day throughout the semester!

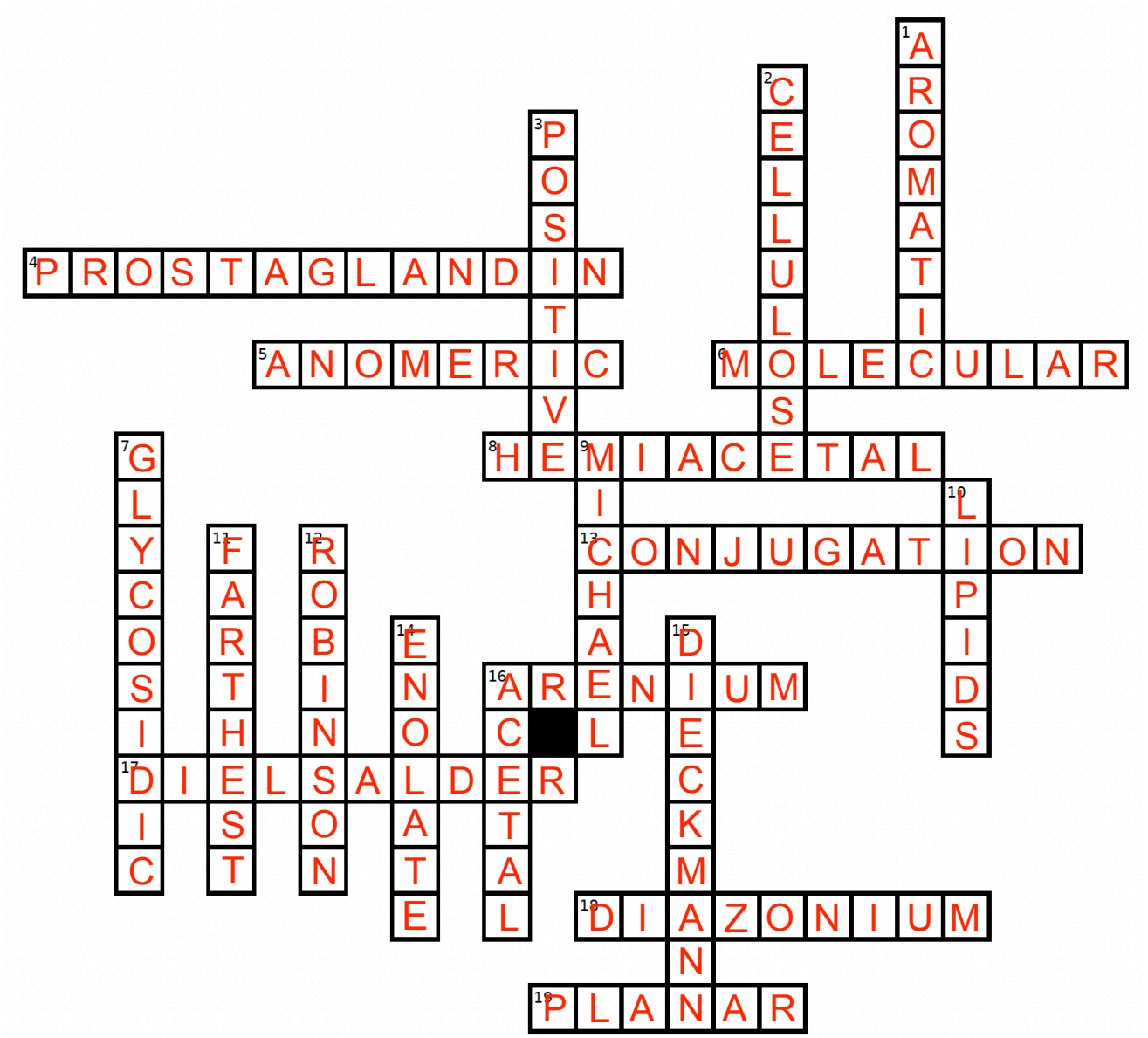
DOWN

1. According to Huckel's rules, for a molecule to be _____ all ring atoms are sp^2 hybridized, the ring must be flat, monocyclic and it must have "4n + 2" pi electrons (2,6,10,...) where n = 0,1,2,3,...).
2. _____ has the glucose monomers linked via beta(equatorial) glucose linkages so it is flat and the chains can pack together nicely.
3. The arenium ion intermediate has partial _____ charge located otho and para to the position of the incoming electrophile, but not meta.
7. Carbohydrate monomers can be linked together via acetal bonds and this linkage can be alpha or beta (For glucose alpha is axial). This type of acetal bond is called a _____ bond.
9. The mechanism of the _____ reaction involves attack by the enolate at the beta-carbon atom to generate a new enolate intermediate, that is reprotonated during the reaction to give an enol, that tautomerizes to the keto form.
10. _____ are biological molecules that are not soluble in water.
11. A D-carbohydrate has the same configuration as (+)-D-glyceraldehyde at the chiral center _____ from the carbonyl group**.**
12. The _____ annulation is a Michael reaction followed by an aldol reaction to make a six-membered ring, ending with a dehydration.
14. When a catalytic amount of base is added to an aldehyde, the _____ that is formed reacts with an aldehyde carbonyl via mechanism A to create a new carbon-carbon bond.
15. A _____ reaction is a cyclic version of the Claisen condensation in which a diester reacts to give a 5 or 6-membered ring
16. Alcohols are weak nucleophiles so they add to aldehydes/ketones only with acid catalysis. Mechanism D is the first part of the mechanism. This mechanism is important! First one, then two alcohol molecules add to give a hemiacetal and an _____, respectively.

ACROSS

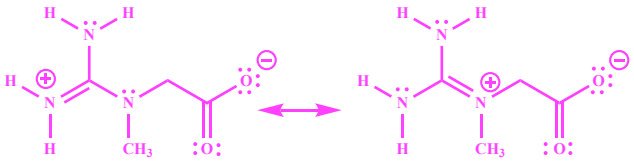
4. A steroid is a rigid scaffold for highly specific hormone molecules while a _____ is a local signaling molecule and the target of non-steroidal anti-inflammatory drugs (NSAIDS) such as aspirin, motrin and tylenol
5. A new chiral center is created at the _____ carbon as the carbohydrate cyclizes, and the OH group can be axial (alpha equals axial for glucose) or equatorial (beta equals equatorial for glucose)**.**
6. When adding wave equations, you generate as many new _____ orbitals as atomic orbitals used to create them.
8. A cyclic _____ that forms a five- or six-membered ring is stable, as opposed to a non-cyclic _____ that is not a stable species. (The same word is used twice in this sentence.)
13. Provided all the atoms are in the same plane, all adjacent 2p orbitals overlap, allowing the pi electron density to delocalize into all the adjacent 2p orbtials**,** their wave functions adding constructively to provide for extra stability. This situation is officially referred to as _____.
16. Electrophilic aromatic substitution involves wicked strong electrophiles reacting with the aromatic pi system to create a resonance stabilized _____ ion intermediate that then loses a proton to give the substitution product.
17. The _____ reaction creates two C-C bonds from a diene and dienophile, an alkene. Hint: leave out the hyphen (-) when writing the answer in the crossword puzzle.
18. Reacting an aromatic amine (like aniline) with $NaNO_2$/HCl converts the NH_2 group into a _____ group (N^{2+}) the famous "Mr. Bill" reaction (HONO!!!!).
19. Because of pi delocalization, an amino group attached to a benzene ring is close to or fully sp2 hybridized. This explains why the DNA bases are _____!

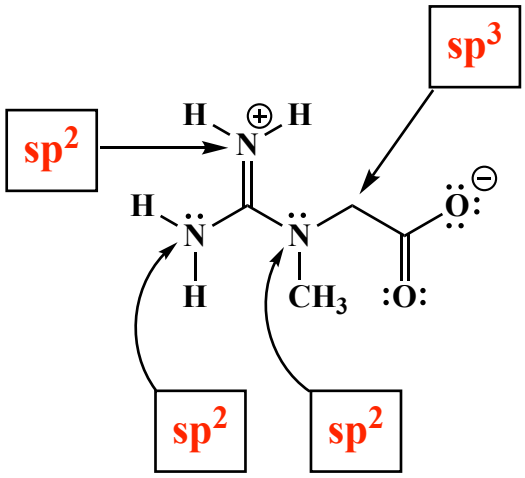
4 (cont.). (2 pts each). Here is an OChem II Crossword puzzle! Fill in the words that are missing based on the clues on Page 2. You will likely recognize these as Rules of the Day throughout the semester!



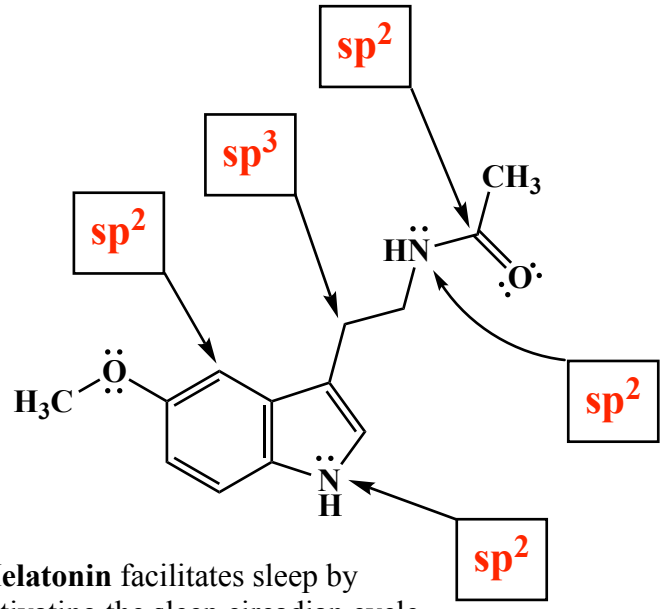
5. (2 pts each) For each arrow, in the box provided write the hybridization state of the atom indicated. Appropriate answers might be sp, sp^2, or sp^3.

These two other contributing structures need to be considered



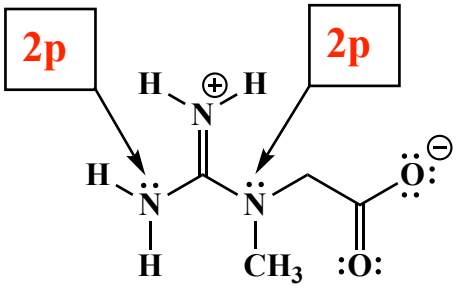


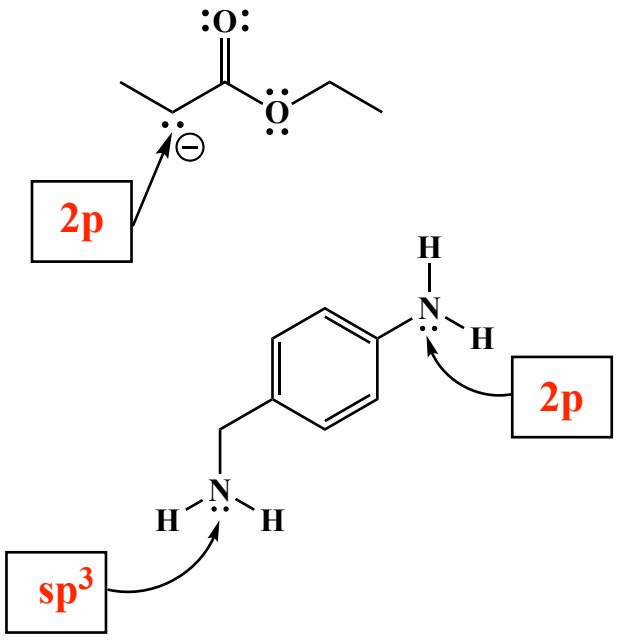
Creatine, the dietary supplement, operates to transfer a phosphate group to ATP in cells



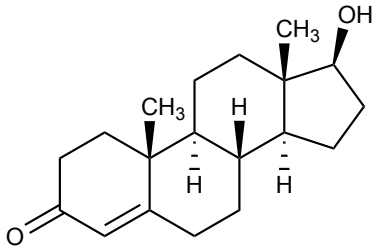
Melatonin facilitates sleep by activating the sleep circadian cycle usually initiated by darkness.

6. (2 pts each) For each arrow, on the line provided write the type of atomic orbital that contains the lone pair of electrons indicated. Appropriate answers might be sp, sp^2, sp^3 or 2p.

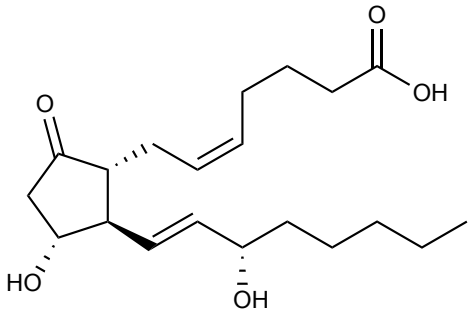




7. (4 pts each) Fill in the circle under each molecule that correctly identifies what kind of molecule is shown immediately above.



- ● This is a steroid - Testosterone
- ○ This is a phospholipid - mammalian membranes
- ○ This is a terpene - from carrots
- ○ This is a triglyceride - Omega-3 from salmon oil
- ○ This is a prostaglandin - PEG_2



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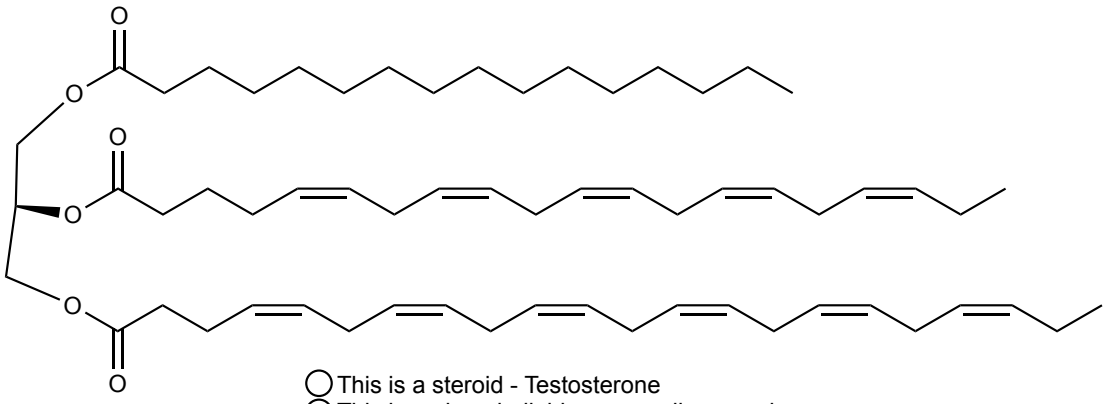

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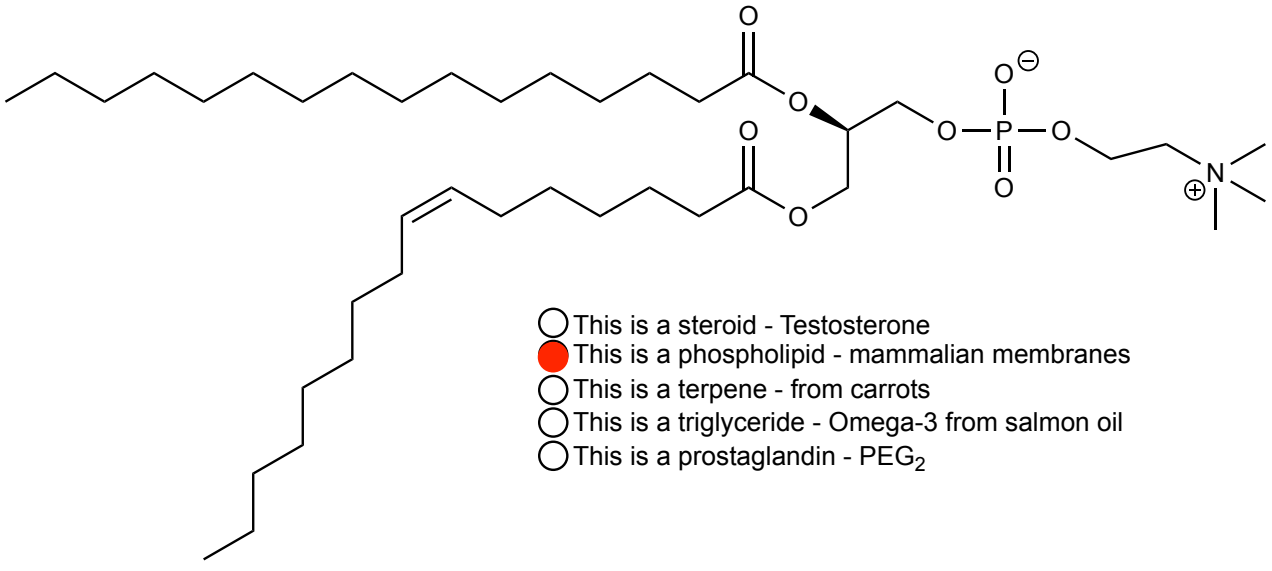

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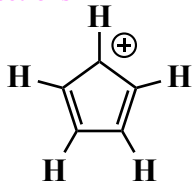
8. (2 pts each) For each pair of molecules, fill in the approporiate circle to indicate the correct description of the molecule drawn immediately above.

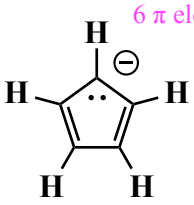
A.

4 π electrons



○ **Aromatic**

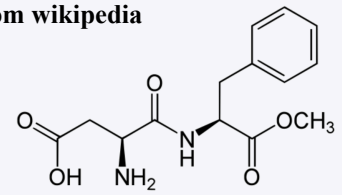
6 π electrons



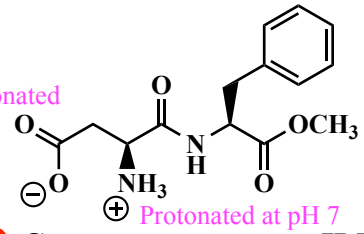
● **Aromatic**

B. Here is the strucure of the sweeetener Aspartame from wikipedia, so not surprisingly this structure is not entirely correct. Aspartame is 100 - 200 times sweeter than sucrose. Indicate the correct structure of Aspartame at pH 7.0

From wikipedia

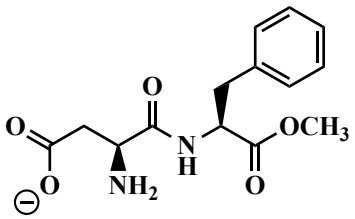


Deprotonated at pH 7



Protonated at pH 7

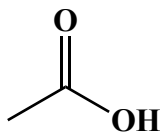
● **Correct structure at pH 7.0**



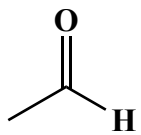
○ **Correct structure at pH 7.0**

C.

More stable anion



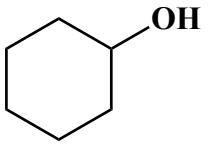
● **Stronger Acid**



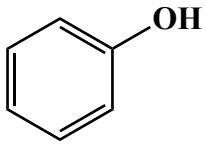
○ **Stronger Acid**

D.

More stable anion



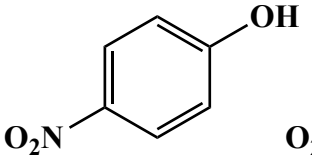
○ **Stronger Acid**



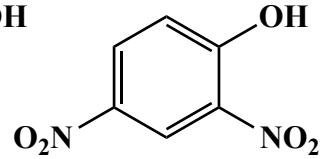
● **Stronger Acid**

E.

More stable anion



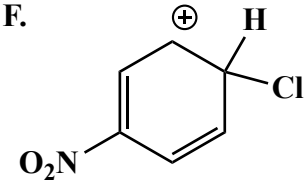
○ **Stronger Acid**



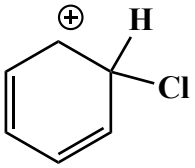
● **Stronger Acid**

F.

Need to consider the other contributing structures



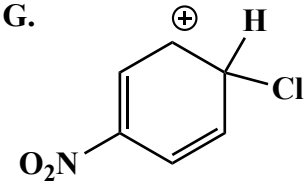
○ **More Stable Ion**



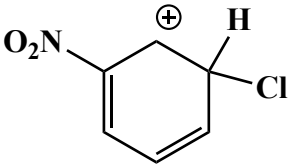
● **More Stable Ion**

G.

Need to consider the other contributing structures



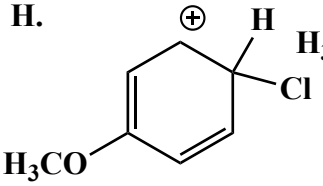
○ **More Stable Ion**



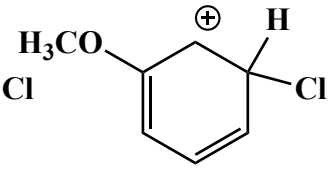
● **More Stable Ion**

H.

Need to consider the other contributing structures



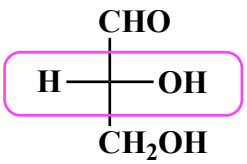
● **More Stable Ion**



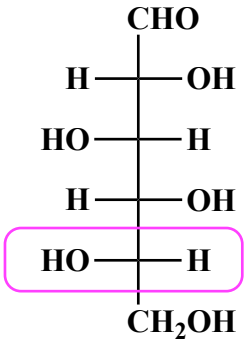
○ **More Stable Ion**

9. (2, 3 or 4 pts each) For each set of molecules, fill in the circles that correctly describe the situation.

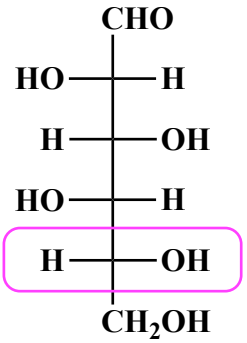
A)



D-Glyceraldehyde

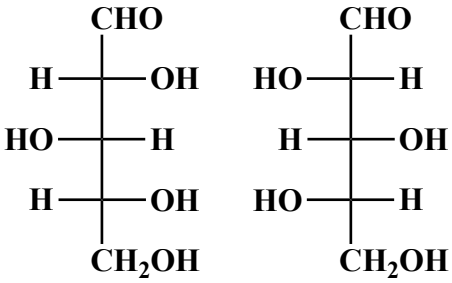


○ D-Carbohydrate
● Not a D-carbohydrate



● D-Carbohydrate
○ Not a D-Carbohydrate

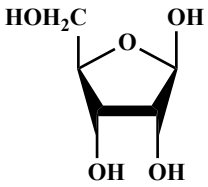
B)



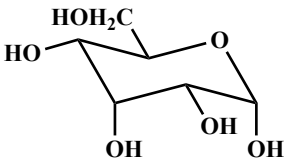
All the chiral centers are inverted

● Enantiomers
○ Diastereomers

C)

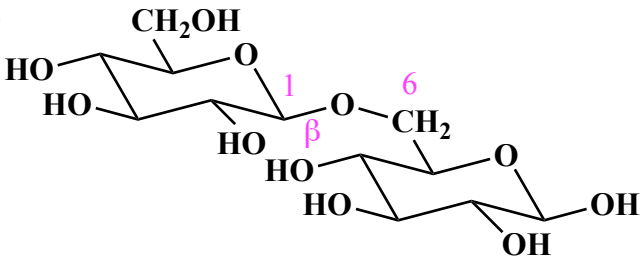


● Furanose
○ Pyranose



○ Furanose
● Pyranose

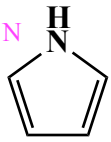
D)



○ This molecule has an α(1,6) glycosidic bond
● This molecule has a β(1,6) glycosidic bond
○ This molecule has an α(1,4) glycosidic bond

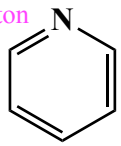
E)

Lone pair on N part of aromatic pi system



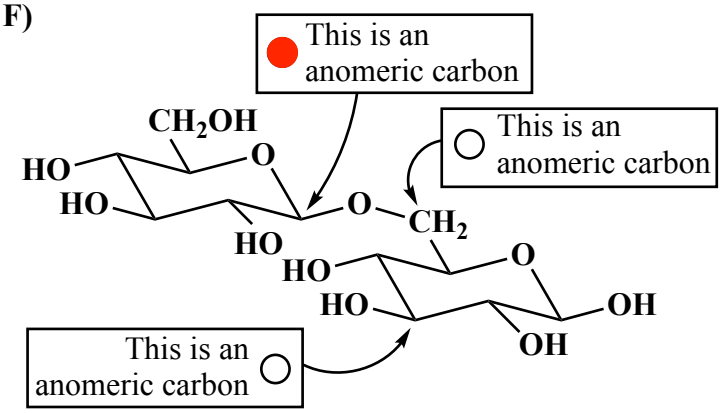
○ Can be used as a base
● Not a base

Lone pair on N available to bind a proton



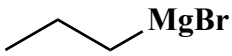
● Can be used as a base
○ Not a base

F)



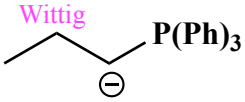
G)

Grignard



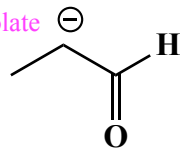
● Nucleophile
○ Electrophile

Wittig

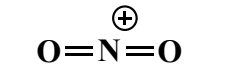


● Nucleophile
○ Electrophile

Enolate

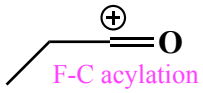


● Nucleophile
○ Electrophile



Nitration intermediate

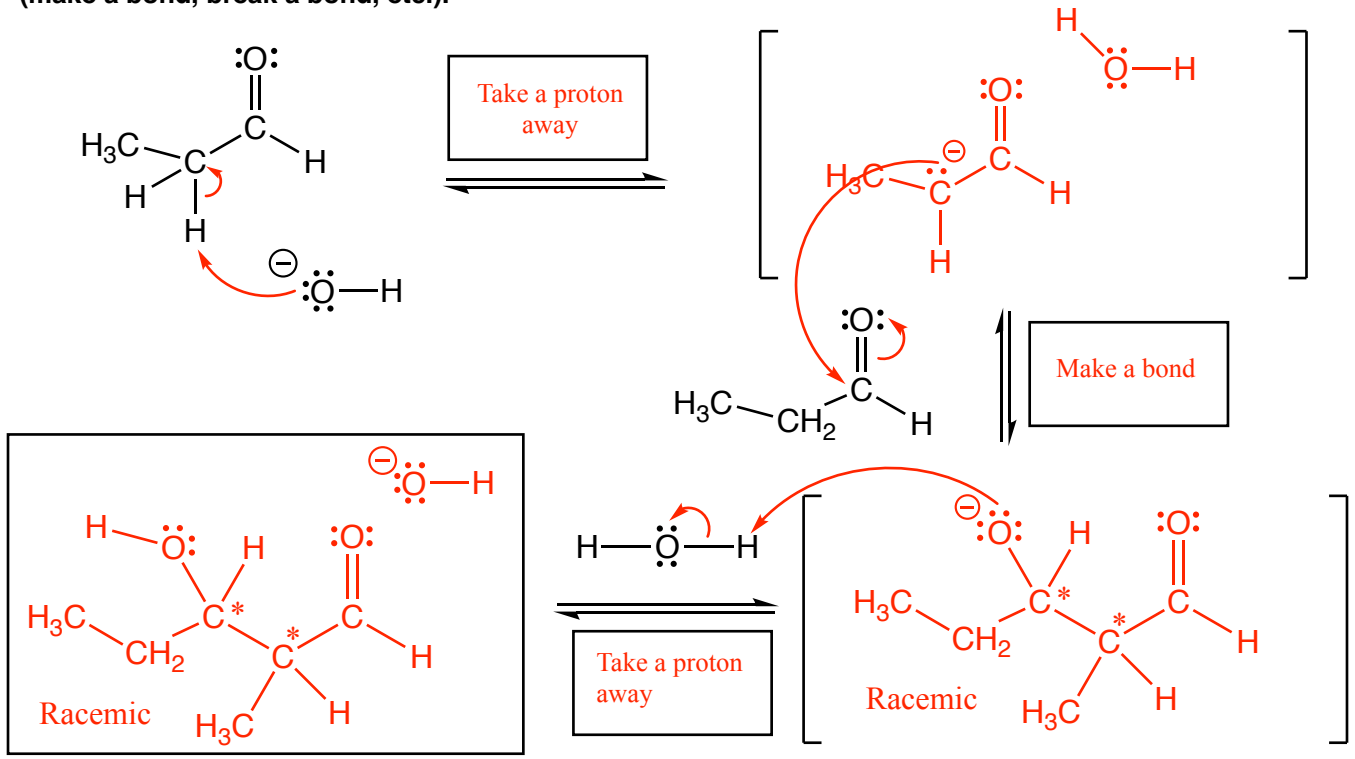
○ Nucleophile
● Electrophile

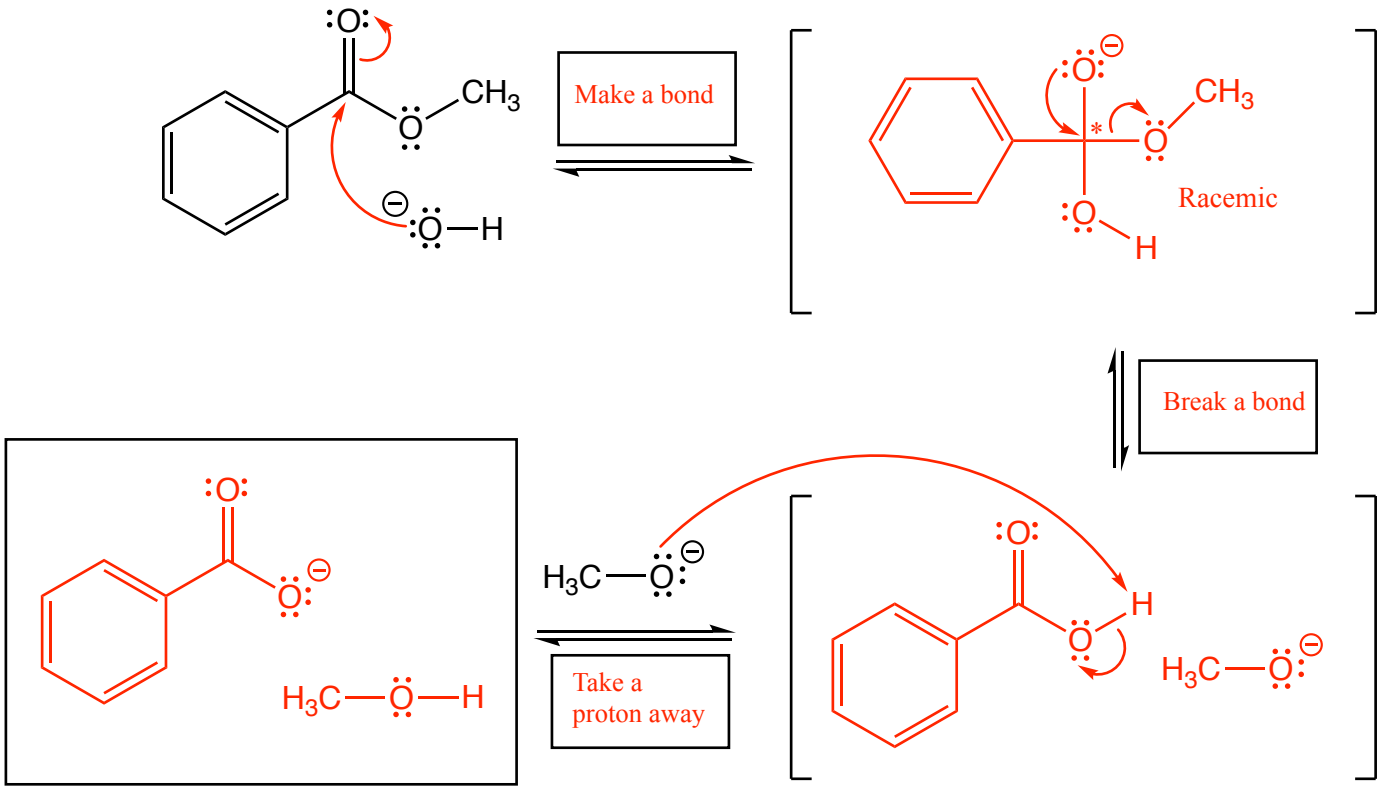


F-C acylation intermediate

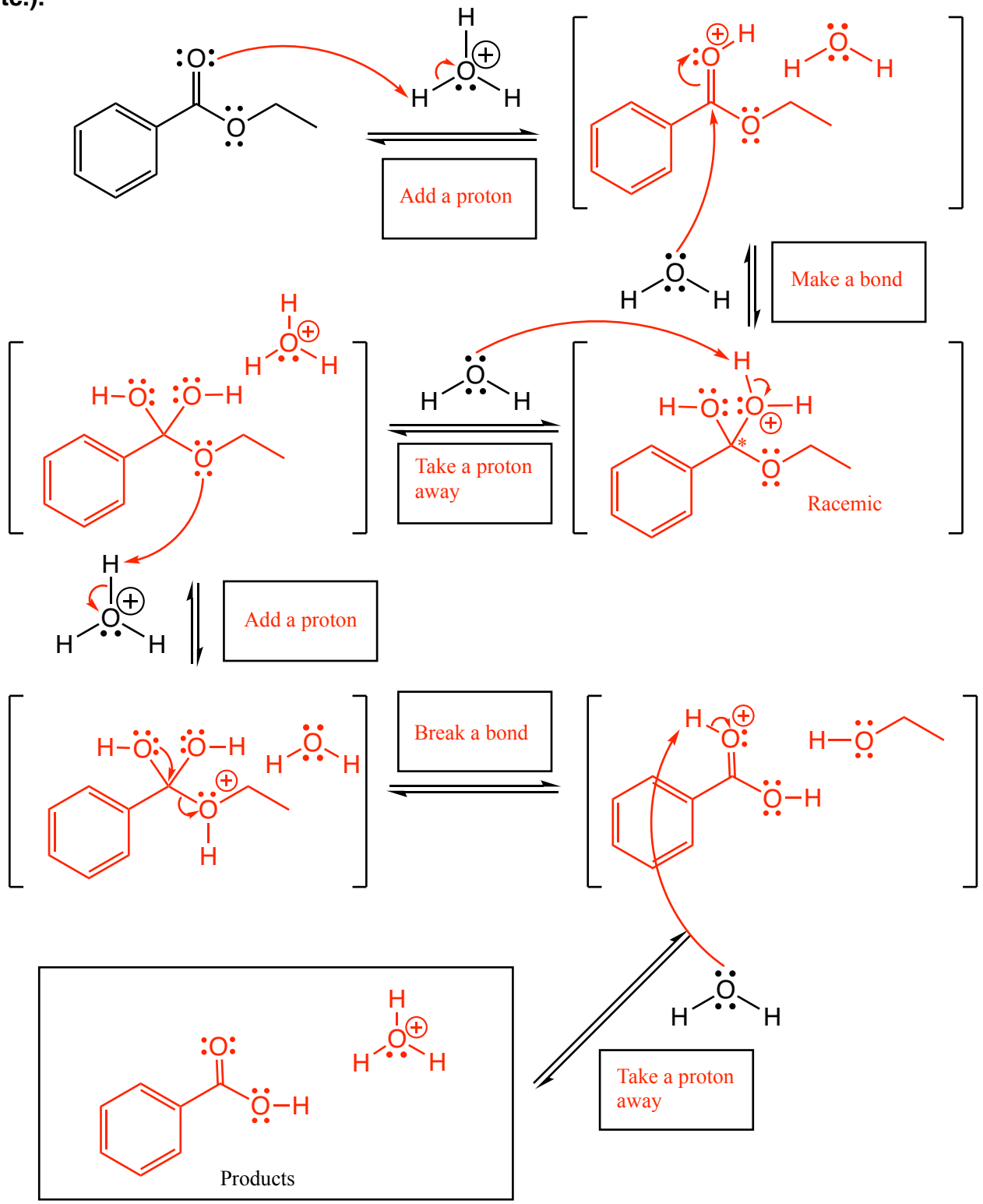
○ Nucleophile
● Electrophile

10. (34 pts) Complete the mechanisms for the following aldol and saponification reactions. **Be sure to show arrows to indicate movement of all electrons, write all lone pairs, all formal charges, and all the products for each step.** Remember, I said all the products for each step. **IF A NEW CHIRAL CENTER IS CREATED IN AN INTERMEDIATE OR PRODUCT, MARK IT WITH AN ASTERISK AND LABEL THE MOLECULE AS RACEMIC IF APPROPRIATE. In the boxes provided, write which of the 4 mechanistic elements describes each step (make a bond, break a bond, etc.).**

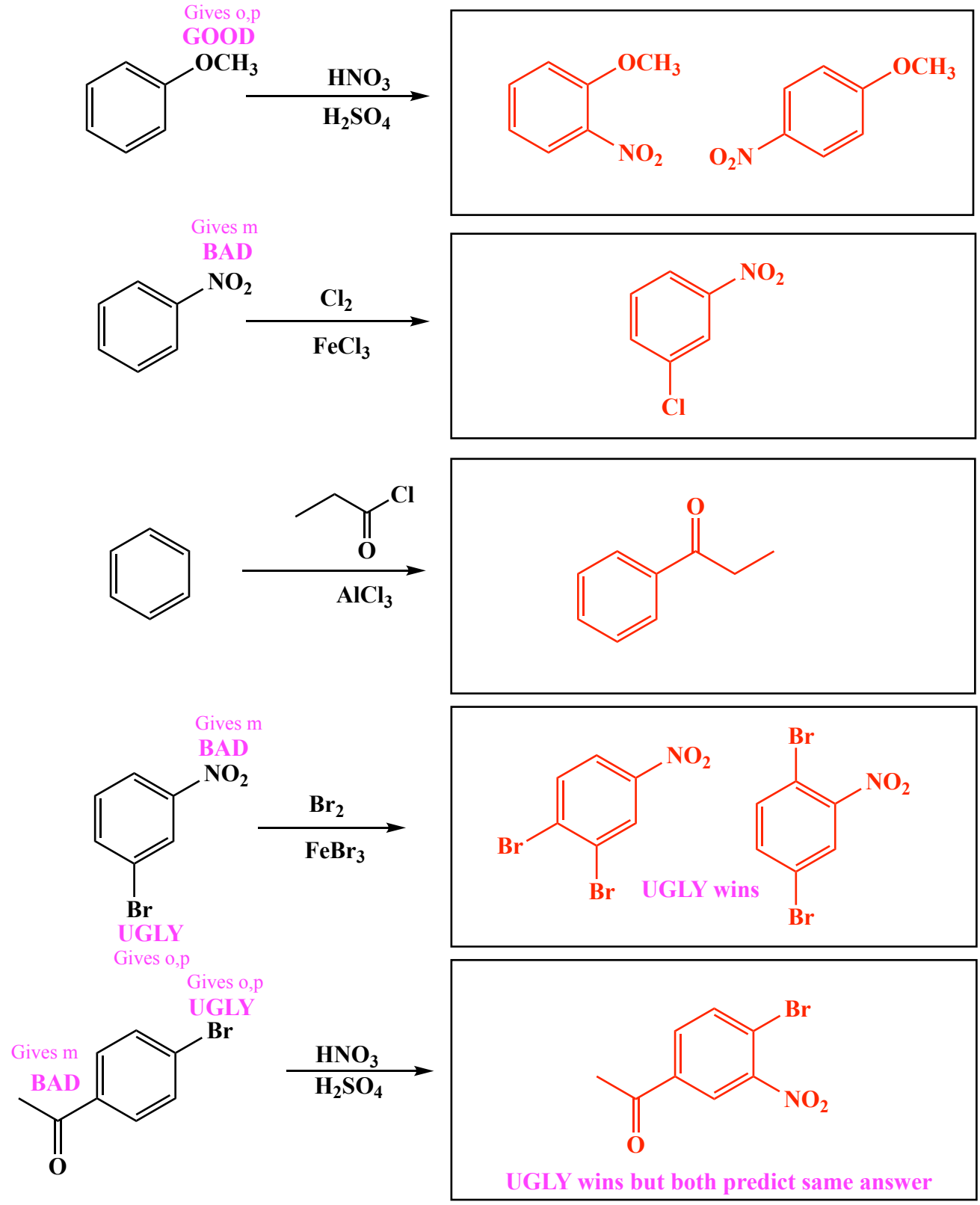




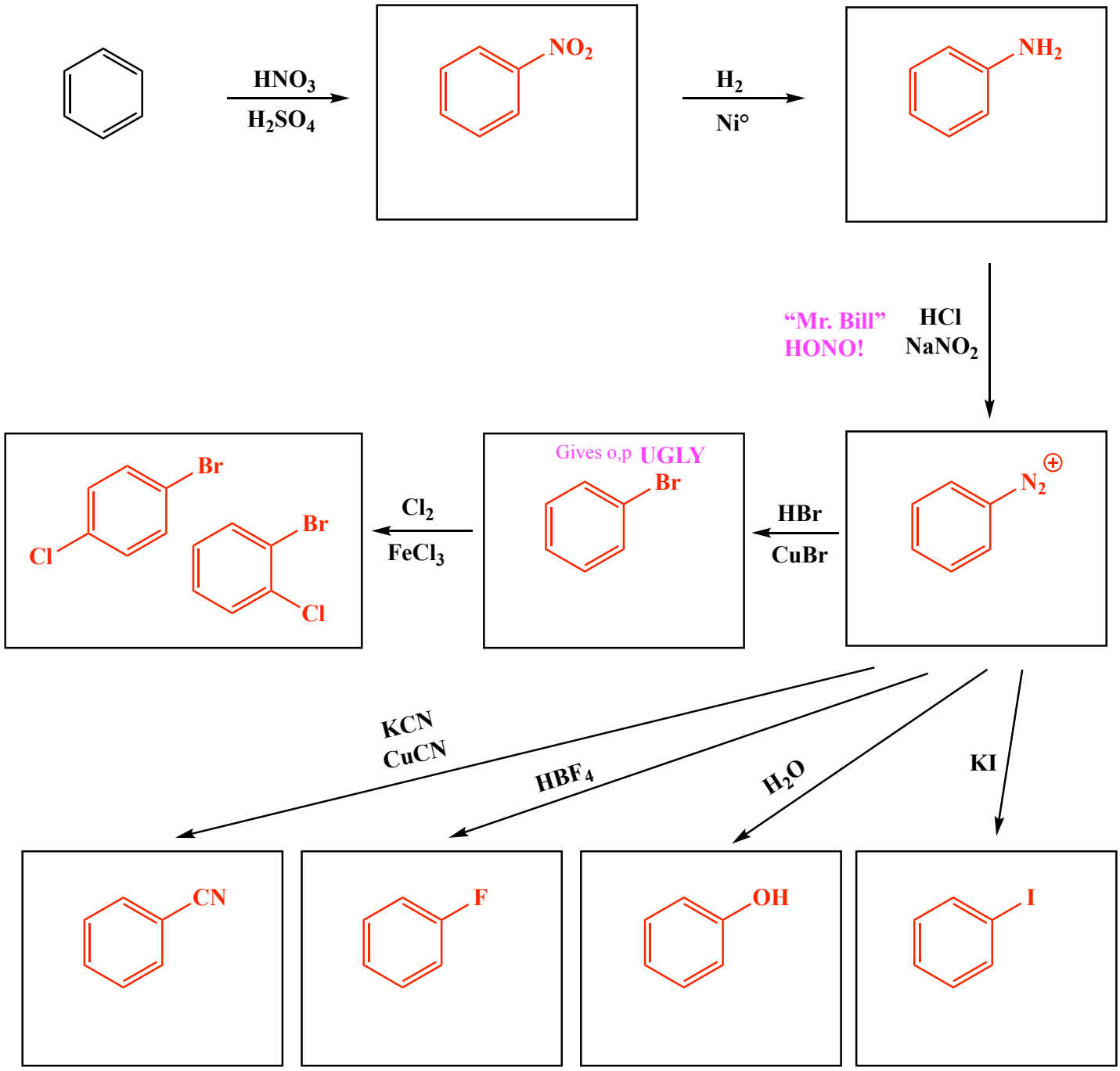
11. (34 pts) Complete the mechanism for the following ester hydrolysis. **Be sure to show arrows to indicate movement of <u>all</u> electrons, write <u>all</u> lone pairs, <u>all</u> formal charges, and <u>all</u> the products for each step.** Remember, I said <u>all</u> the products for each step. **IF A NEW CHIRAL CENTER IS CREATED IN AN INTERMEDIATE OR PRODUCT, MARK IT WITH AN ASTERISK AND LABEL THE MOLECULE AS RACEMIC IF APPROPRIATE. In the boxes provided, write which of the 4 mechanistic elements describes each step (make a bond, break a bond, etc.).**



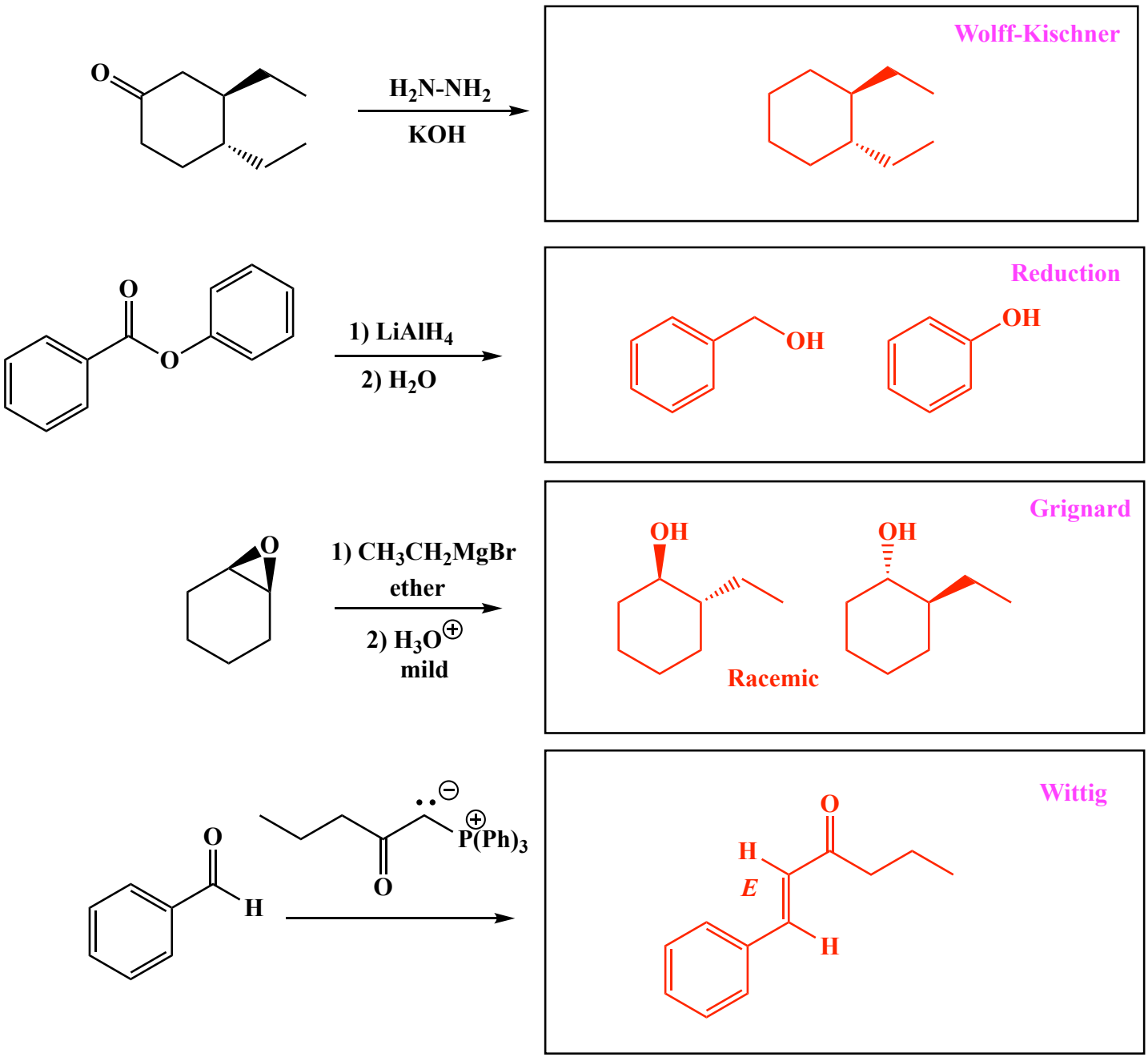
12. (3 or 5 pts.) Write the predominant product(s) that will occur for each transformation. If a new chiral center is created and a racemic mixture is formed, you must draw both enantiomers and write "racemic" under the structure. Use wedges (◀) and dashes (····ıı) to indicate stereochemistry. For these, only write the principle organic products, do not include side products like ethanol, CO_2 or metal salts. **For all aldol reactions, we only want you to draw the dehydrated products.**



12 (cont.) (3 or 5 pts.) Write the predominant product(s) that will occur for each transformation. If a new chiral center is created and a racemic mixture is formed, you must draw both enantiomers and write "racemic" under the structure. Use wedges (◄) and dashes (·····) to indicate stereochemistry. For these, only write the principle organic products, do not include side products like ethanol, CO_2 or metal salts. **For all aldol reactions, we only want you to draw the dehydrated products.**

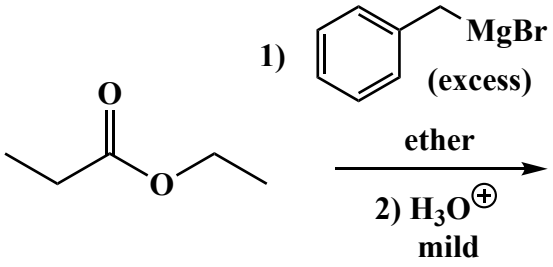


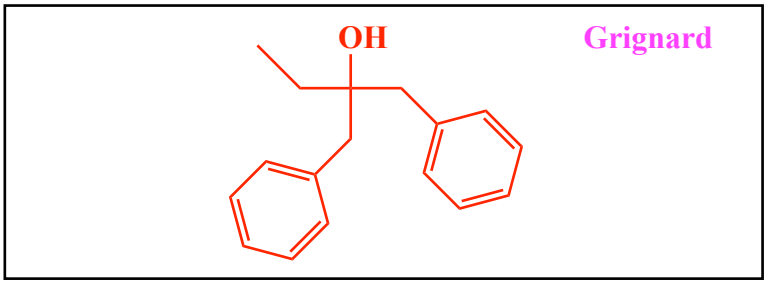
12 (cont.) (3 or 5 pts.) Write the predominant product(s) that will occur for each transformation. If a new chiral center is created and a racemic mixture is formed, you must draw both enantiomers and write "racemic" under the structure. Use wedges (◀) and dashes (·····) to indicate stereochemistry. For these, only write the principle organic products, do not include side products like ethanol, CO_2 or metal salts. **For all aldol reactions, we only want you to draw the dehydrated products.**



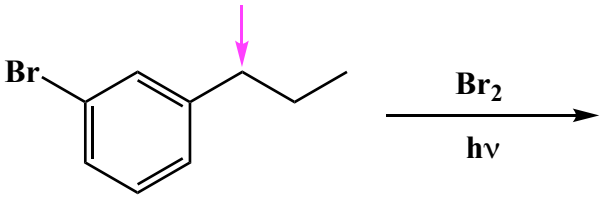
e

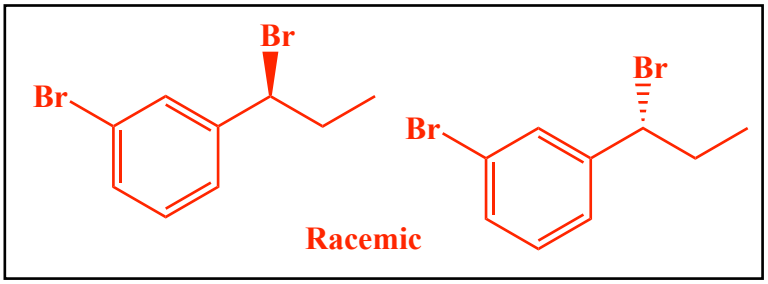
12 (cont.) (3 or 5 pts.) Write the predominant product(s) that will occur for each transformation. If a new chiral center is created and a racemic mixture is formed, you must draw both enantiomers and write "racemic" under the structure. Use wedges (◄) and dashes (····|||) to indicate stereochemistry. For these, only write the principle organic products, do not include side products like ethanol, CO_2 or metal salts. **For all aldol reactions, we only want you to draw the dehydrated products.**

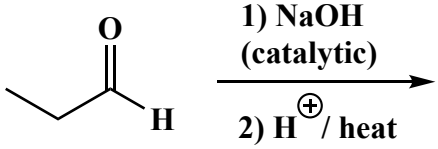


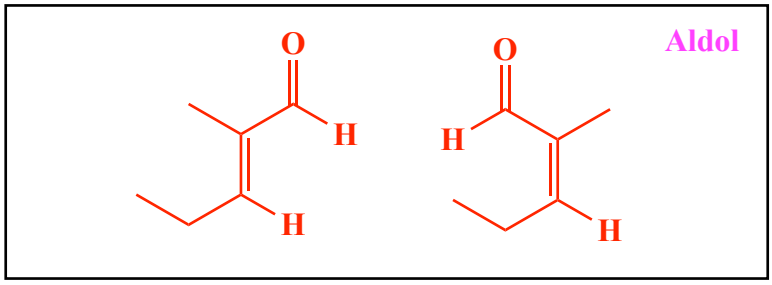


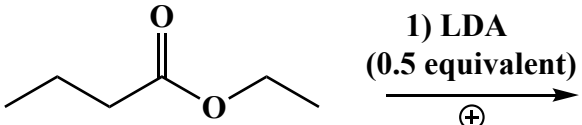
The benzylic H atoms are most reactive because the benzylic radicsl is so stable

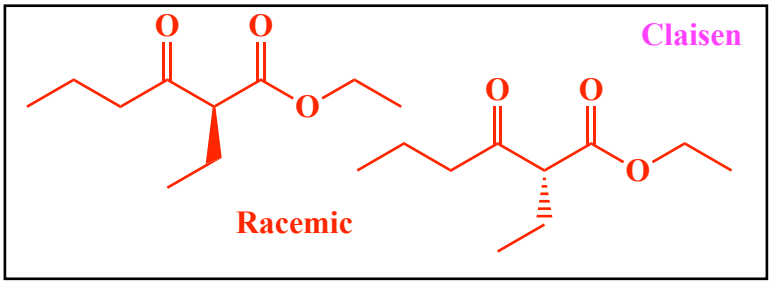


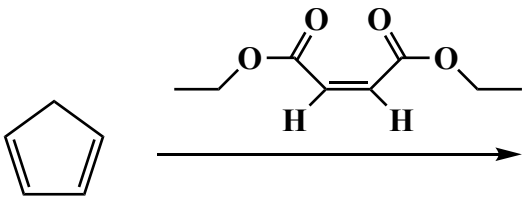


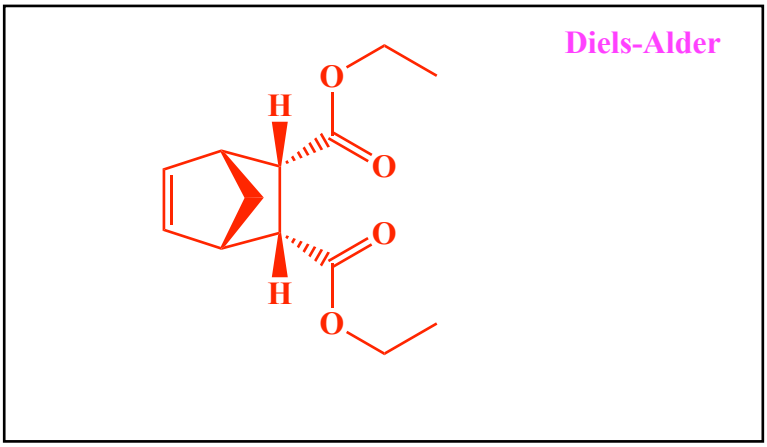




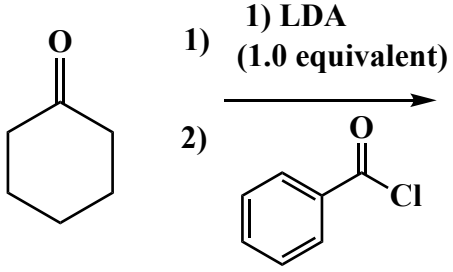


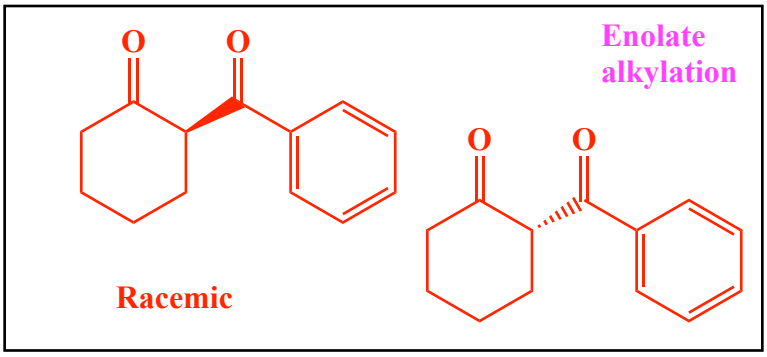


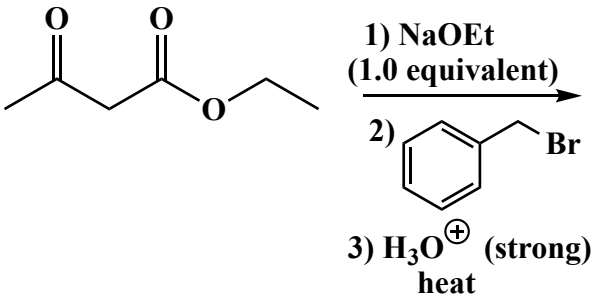


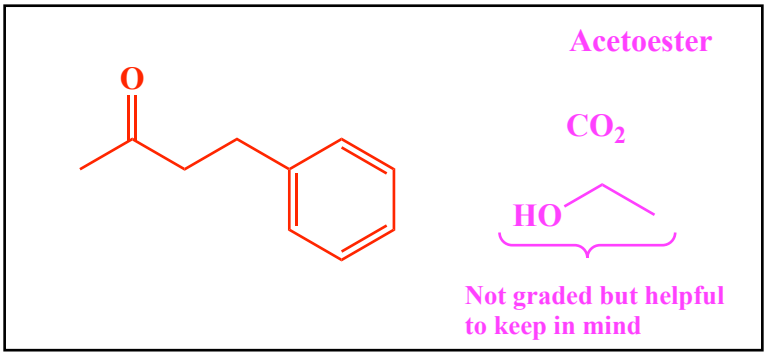


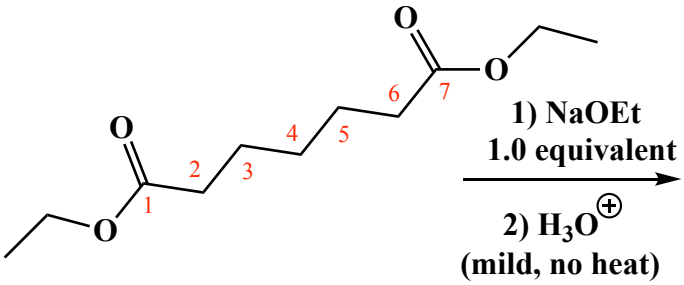
12 (cont.) (3 or 5 pts.) Write the predominant product(s) that will occur for each transformation. If a new chiral center is created and a racemic mixture is formed, you must draw both enantiomers and write "racemic" under the structure. Use wedges (◄) and dashes (·····) to indicate stereochemistry. For these, only write the principle organic products, do not include side products like ethanol, CO_2 or metal salts. **For all aldol reactions, we only want you to draw the dehydrated products.**

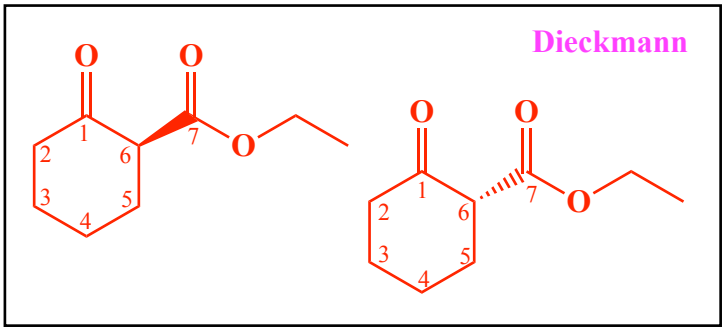


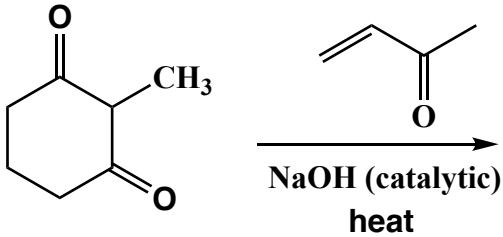


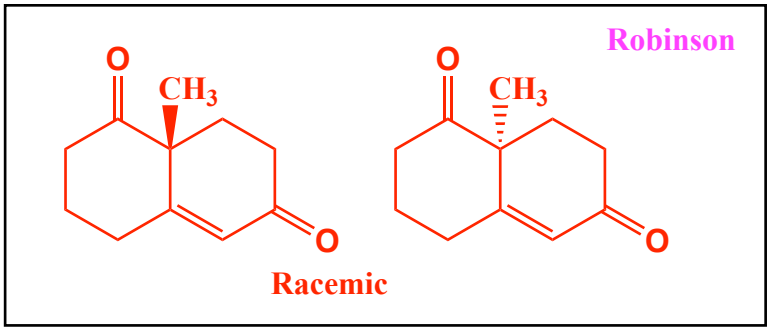






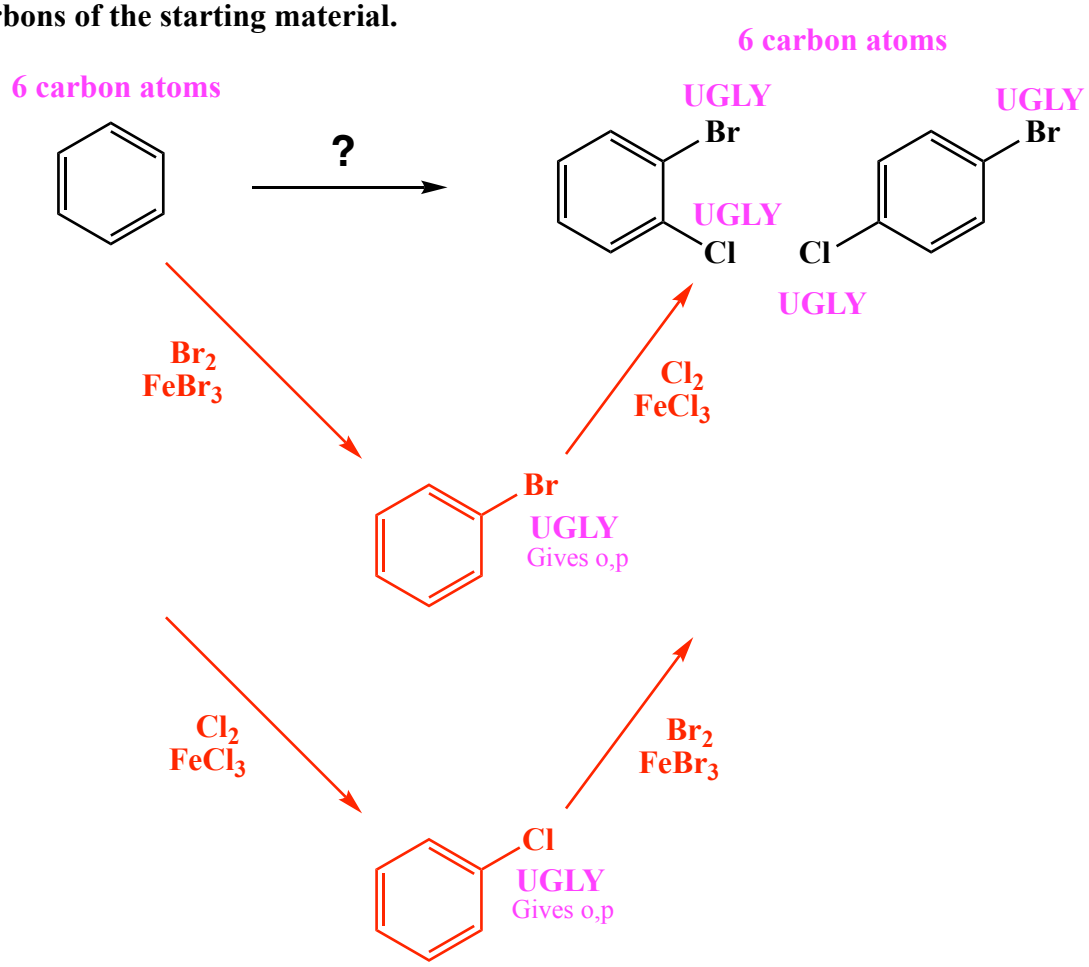






13. These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate. **All the carbons of the product must come from carbons of the starting material.**

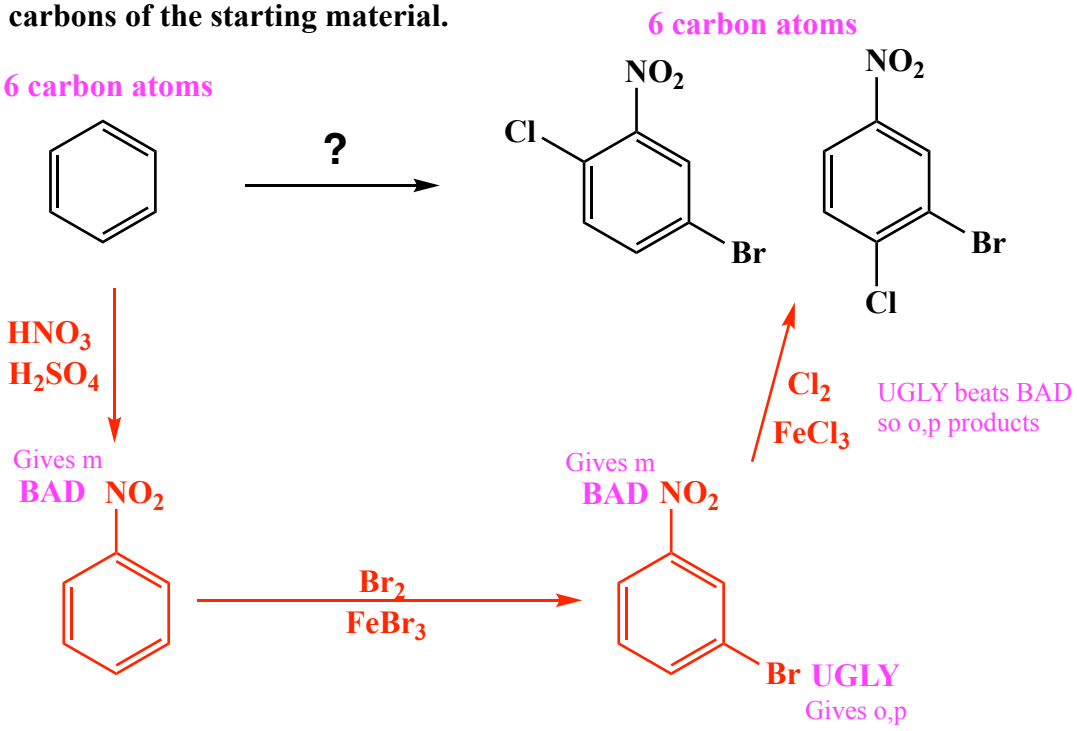
A) (4 pts)



Recognize that the product has two UGLY groups that are both ortho and para directing. Since both predict the same ortho and para products that are present, it does no matter which one you add first. Both answers give full credit.

13. These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate. **All the carbons of the product must come from carbons of the starting material.**

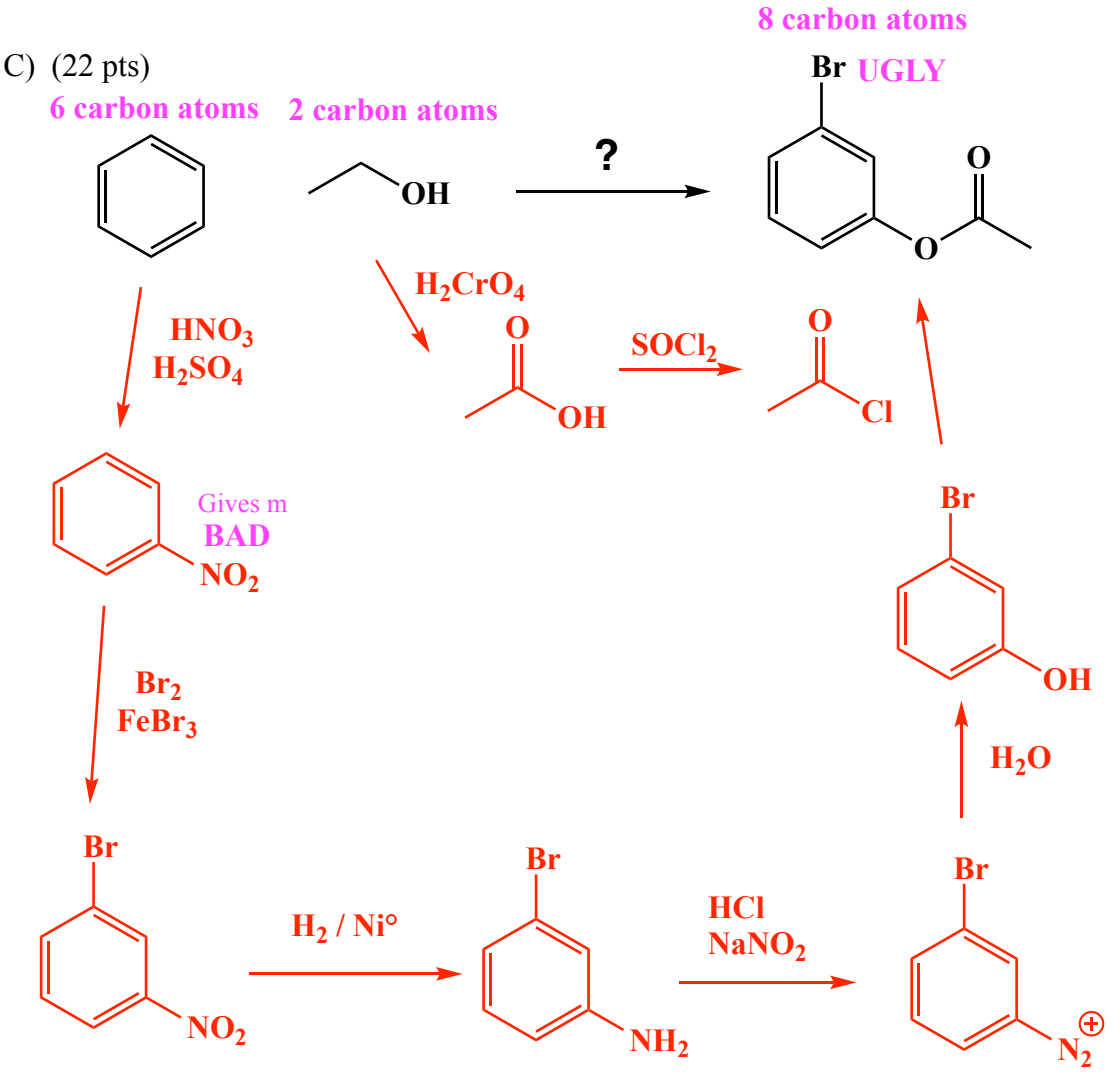
B) (7 pts)



Recognize that only one sequence of reactions gives the desired two products. In particular, **recognize** that in the products the Cl atoms are ortho and para to the Br atom, while the -NO_2 and Br atoms are meta in both productes. So the Cl group had to be added last using Cl_2 and $FeCl_3$, starting with meta -NO_2 and Br. Make this meta product by adding Br to nitrobenzene using Br_2 and $FeBr_3$. Nitrobenzene comes from using HNO_3 and H_2SO_4 with the benzene starting material. Note that if you tried this by first adding the Cl group followed by NO_2 and then Br, you would get two of the same products, but an additional (third) one as well so that will not work.

13. These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate. **All the carbons of the product must come from carbons of the starting material.**

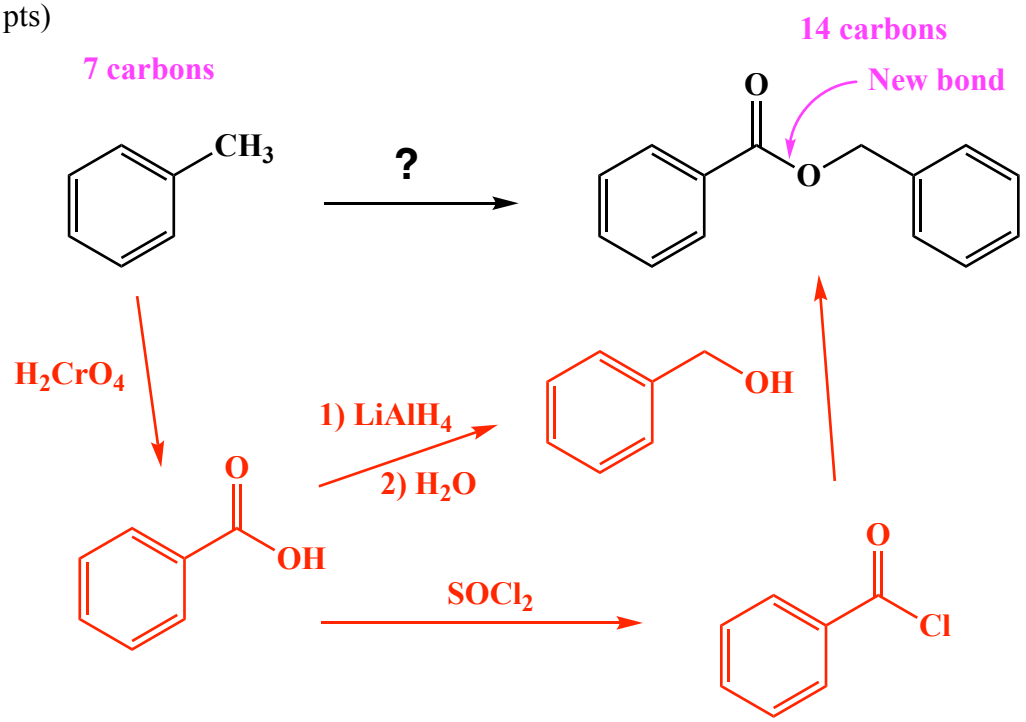
C) (22 pts)



Recognize that the product has 8 carbons, so you need to use both starting materials. **Recognize** the product has one UGLY and one GOOD group that are meta to each other, so there is no way to make this product using electrophilic aromatic substitution reactions directly. Instead, assume you need to call "Mr. Bill" and use a diazonium reaction. Further, recognize the product is an ester, and you cannot add those directly using the Mr. Bill reaction, but you can add an OH groud then make the ester with acetyl chloride in the last step. Acetyl chloride can be made from the starting alcohol using H_2CrO_4 to give the carboxylic acid followed by $SOCl_2$. Assume the only way to get the required meta-substituted bromo diazonium derivative is to start with a nitration reaction using HNO_3 and H_2SO_4, putting the BAD nitro group on first followed by the Br_2 $FeBr_3$ reaction to give meta substitution. H_2/Ni followed by "Mr. Bill, HONO!!!" (HCl, $NaNO_2$) gives the needed meta-substituted diazonium. As always, you could have cut out one step by reaction acetic acid with 2-bromophenol in the presence of catayltic H_2SO_4 to give the ester via Fischer sseterification.

13. These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate. **All the carbons of the product must come from carbons of the starting material.**

D) (10 pts)

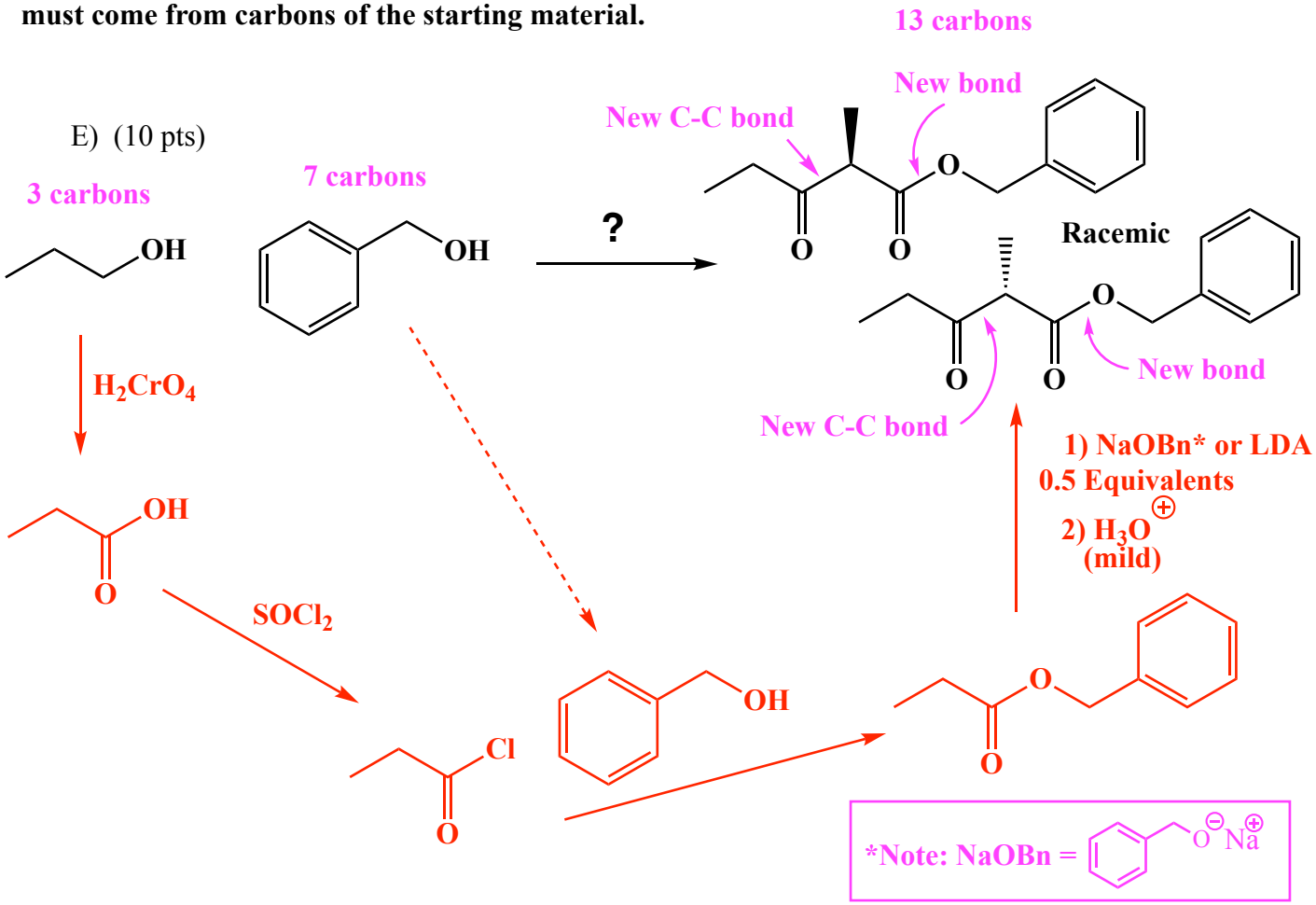


Recognize that the product has 14 carbons, so you need to use two of the starting molecules. **Recognize** further the product is an ester and that the only bond you can make is the C-O bond as shown. Therefore predict that the last step is reaction between benzoyl chloride and benzyl alchol as shown. A simple way to make the required acid chloride and alcohol is to start with benzoic acid, and react that with $SOCl_2$ or 1) $LiAlH_4$ 2)H_2O, respectively. The benzoic acid can be made from the starting toluene molecule using chromic acie as shown. As always, you could have cut out one step by reaction benzoic acid with benzyl alcohol in the presence of catayltic H_2SO_4 to give the ester via Fischer sseterification.

Signature_____

13. These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate. **All the carbons of the product must come from carbons of the starting material.**

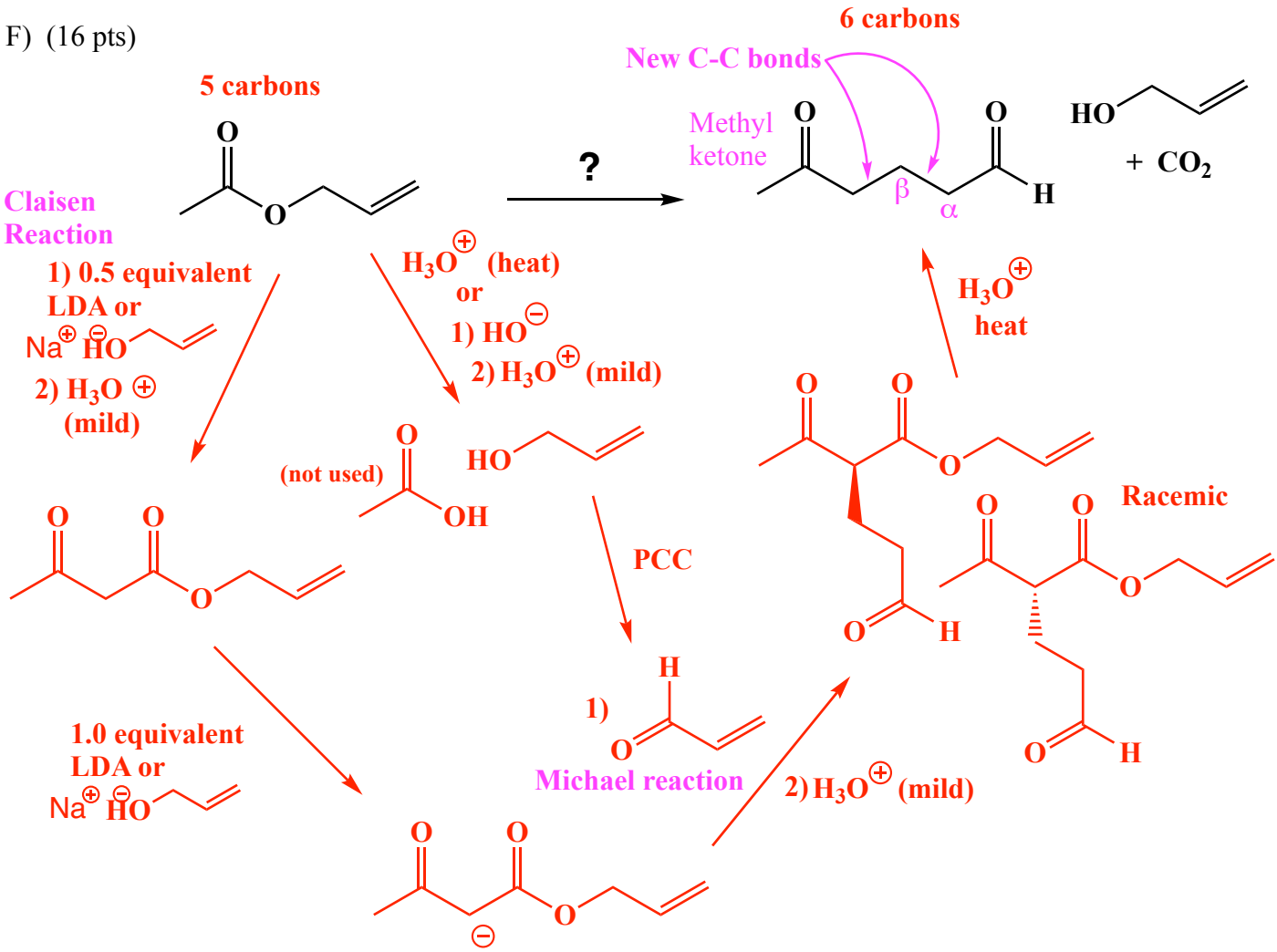
E) (10 pts)



Recognize That the final product has 13 carbons, while the starting materials have 3 and 7 carbons, respectively. **Recognize** further that the product is a β-keto ester, the KRE of a Claisen reaction, so predict there are new C-C and C-O bonds as indicated. **Recognize** that the product Claisen has 6 carbons not counting the 7 carbons of the ester side, so assume there is a Claisen with two of the three carbon units, as the benzyl ester, reacting in the last step. Notice that you can use LDA or NaOBn, the sodium salt of benzyl alcohol, but you cannot use NaOEt as the base here because that would lead to ethyl esters via direct reaction with the ester (so-called transesterificataion). The required benzyl ester can be made from the corresponding three carbon acid chloride and benzyl alcohol, the latter of which is one of the starting materials. The required acid chloride can be made from the 1-propanol by first reacting with chromic acid followed by $SOCl_2$. As always, you could have cut out one step by reaction propionic acid with benzyl alcohol in the presence of catayltic H_2SO_4 to give the ester via Fischer sseterification.

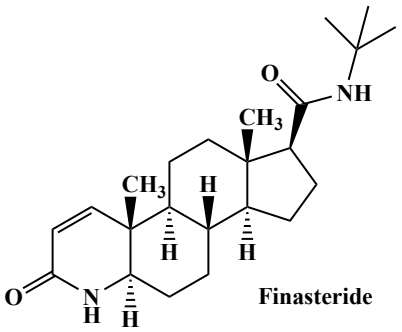
13. These are synthesis questions. You need to show how the starting material can be converted into the product(s) shown. You may use any reactions we have learned provided that the product(s) you draw for each step is/are the predominant one(s). Show all the reagents you need. Show each molecule synthesized along the way and be sure to pay attention to the regiochemistry and stereochemistry preferences for each reaction. You must draw all stereoisomers formed, and use wedges and dashes to indicate chirality at each chiral center. Write racemic when appropriate. **All the carbons of the product must come from carbons of the starting material. (Hint: This was on the third midterm!)**

F) (16 pts)



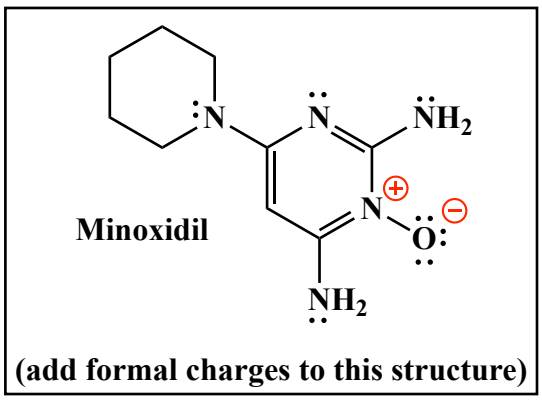
Recognize that the product has 6 carbons and the starting material has 5 carbons, so there will be at least one new C-C bond. **Recognize** the product is a methyl ketone, the KRE of an acetoester synthesis. **Recognize** further that the product has carbonyl groups 5 carbons apart, the KRE of a Michael reaction starting with an enolate. **Recognize** further that there is an alcohol and CO_2 listed as final products, an indication the last step was an ester hydrolysis followed by decarboxylation, consistent with the last step of an acetoester synthsis as shown. **Recognize** that the required substituted β-keto ester for the last step can be made through a Michael reaction using the enolate of the β-keto ester shown with the α,β-unsaturated aldehyde as shown. The required α,β-unsaturated aldehyde can be made from the corresponding alcohol, which itself can be made by hydrolysis of the starting ester using either acid catalysis or reaction with 1) hydroxide, 2) mild acid. The required enolate for the Michael reaction can be made from the starting ester by a Claisen reaction, followed by deprotonation in base.

14. (12 pts total) Here is an "apply what you know" question, the first part of which relates to hair loss treatments and the second part relates to possible causes of cancer. **Minoxidil** treats hair loss primarily by acting as a vasodilator and ATP-sensitive potassium-channel opener in scalp vasculature and follicular cells, which increases blood flow, oxygen, and nutrient delivery to hair follicles and directly promotes and prolongs the anagen (growth) phase, leading to thicker, longer hairs while it is used. **Finasteride** is an oral 5-alpha-reductase type II inhibitor that lowers dihydrotestosterone (DHT) levels in scalp and serum, thereby reducing hormone-driven miniaturization of hair follicles and allowing partially shrunken follicles to enlarge and produce thicker hairs over time. Used together, minoxidil primarily boosts local follicle growth dynamics, whereas finasteride addresses the underlying hormonal driver, providing additive benefit in many men with male-pattern hair loss. Being it is a steroid related to testosterone, finasteride is associated with a number of serious side effects, and a prescription is required.



Finasteride

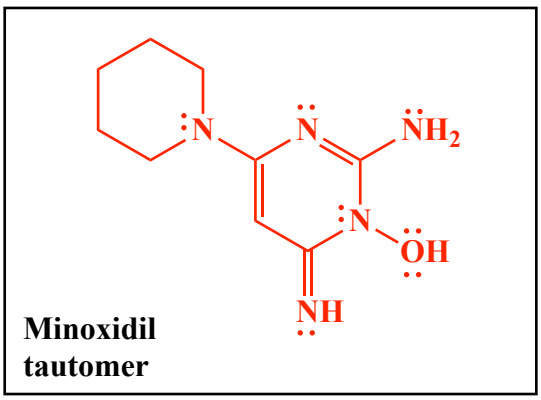
Minoxidil was originally developed and approved as an oral antihypertensive vasodilator (in other words used to treat high blood pressure). During its clinical use in the 1970s, physicians noticed that many patients developed increased hair growth. This unexpected side effect prompted targeted studies of minoxidil on scalp hair, leading to the development of topical minoxidil formulations specifically to increase hair grwoth. So, its role as a hair-loss treatment was discovered serendipitously, then deliberately developed and optimized in products such as Rogaine, Kirkland Signature Minoxidil, Equate Minoxidil, CVS Health Minoxidil, Hims Topical Minoxidil, Keeps Hair Regrowth Treatment and Roman (Ro) Topical Minoxidil.



Minoxidil

(add formal charges to this structure)

Tautomerization

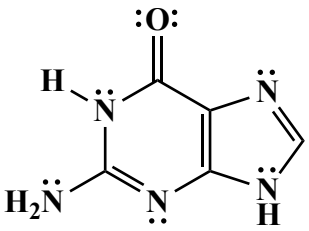


Minoxidil tautomer

(4 pts) Minoxidil has an interesting structure. Above on the left I have drawn minoxidil, complete with all of the lone pairs. However, I have left off the formal charges. **On the structure on the left above, draw any formal charge(s) that are required to make this an accurate Lewis structure.**

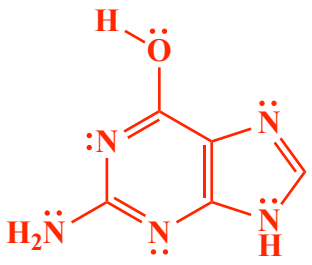
(4 pts) Minoxidil undergoes tautomerization (yep tautomerization, like keto-enol) that should also be mentioned. **Look at the structure of minoxidil above, and draw a reasonable tautomer of the minoxidil structure in the box to the right**. Hint: The tautomer you will draw on the right has no formal charges. This could take you a minute, so feel free to leave it until the end. **Make sure to add all lone pairs to your structure to get full credit**.

(4 pts) Tautomerization is also being studied with the DNA bases. For example, the aromatic base guanine has both a "keto" and "enol" form. The keto form is far more stable and is the one we normally consider because it base pairs with cytosine via three hydrogen bonds. However, guanine does tautomerize to some small extent, to give an enol form. And the guanine enol form base pairs with thymine, not cytosine. Some scientists think the small amount of the guanine enol form pairs with thymine during replication, leading to a mutation. It is rare, but over time it could add up for an organism. **In the box to the right below, draw the enol form of guanine**. **Make sure to add all lone pairs to your structure to get full credit**.



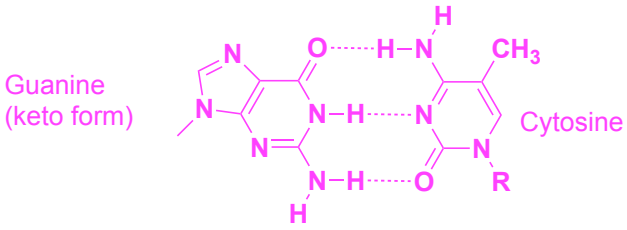
Guanine - keto form

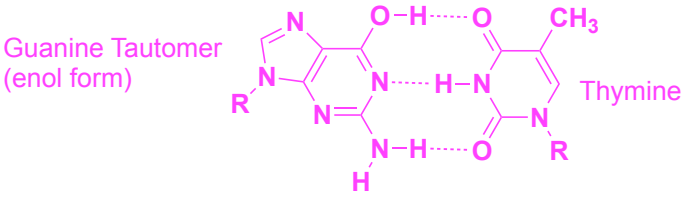
Tautomerization



Guanine - enol form

Here is a paper that discusses this further if you are interested: *Communications Chemistry* **volume 5**, Article number: 144 (2022).





Like I said at the beginning of this exam, it has been an honor to be on this journey of Organic Chemistry discovery and learning with you. Have a wonderful summer break and remember: **Go see something that truly takes your breath away and also….run every chance you get!**