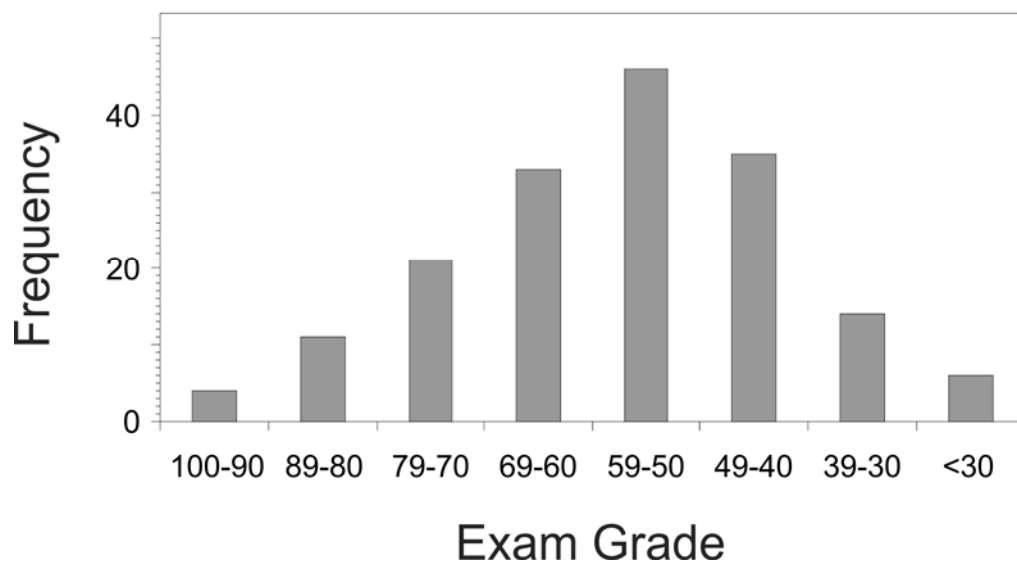


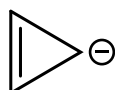
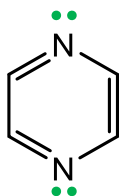
**Exam 1
Answer Key**

Exam 1 Mean: 57
Exam 1 Median: 56
Exam 1 St. Dev.: 15



1. (12 pts) For each of the following molecules, circle whether the molecule is aromatic, anti-aromatic, or neither.

3 **AROMATIC**
ANTI-AROMATIC
NEITHER

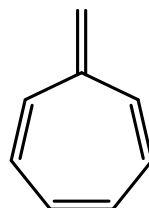
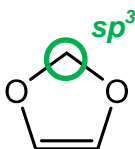


AROMATIC
ANTI-AROMATIC 3
NEITHER

Both of the N atoms in this molecule are naturally sp^2 -hybridized (they don't "re-hybridize"), with the drawn lone pairs occupying one of those sp^2 hybrid orbitals. Because they aren't in p orbitals, the lone pairs don't contribute to the conjugated π system. So, this molecule has just 6 π electrons (from the 3 double bonds), and is aromatic.

This molecule has 4 π electrons—2 from the double bond, and two from the negative charge (which indicates that the right-hand C has a lone pair). That's an even number of pairs, so the molecule is anti-aromatic.

AROMATIC
ANTI-AROMATIC
 3 **NEITHER**

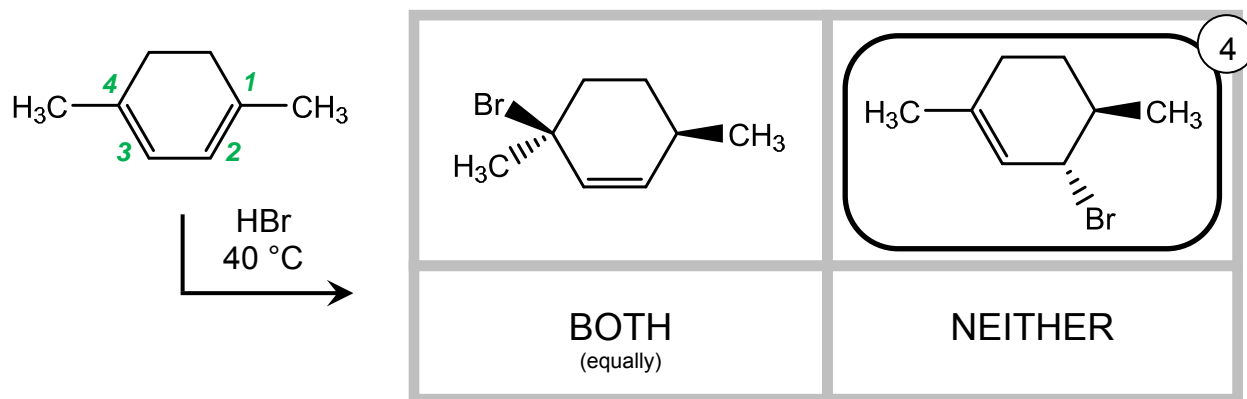


AROMATIC
ANTI-AROMATIC
NEITHER 3

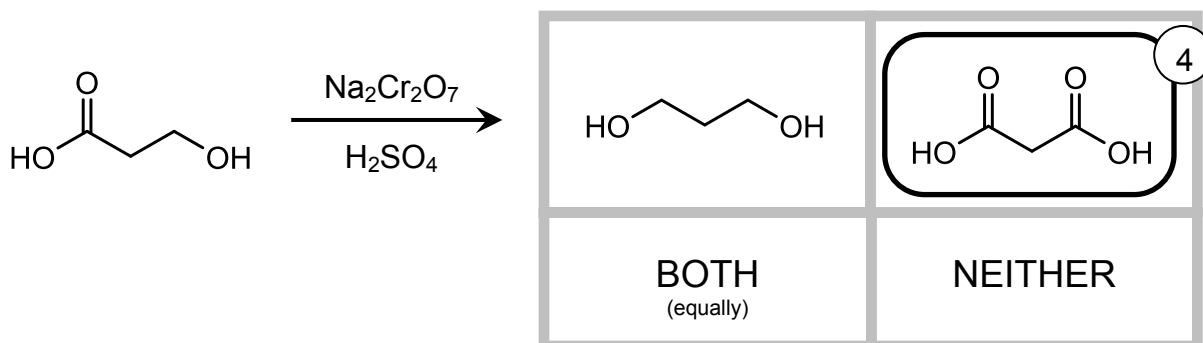
This molecule does not have a complete cycle of p orbitals. As a result, it can't be aromatic or anti-aromatic.

This molecule has 7 π electrons in the ring—6 from the three double bonds in the ring, and 1 from half of the exocyclic (top) π bond. Some of you drew structures in which you pushed the top double bond into the ring or away from it, but neither of these structures satisfies any of the criteria for valid resonance structures, so they don't count.

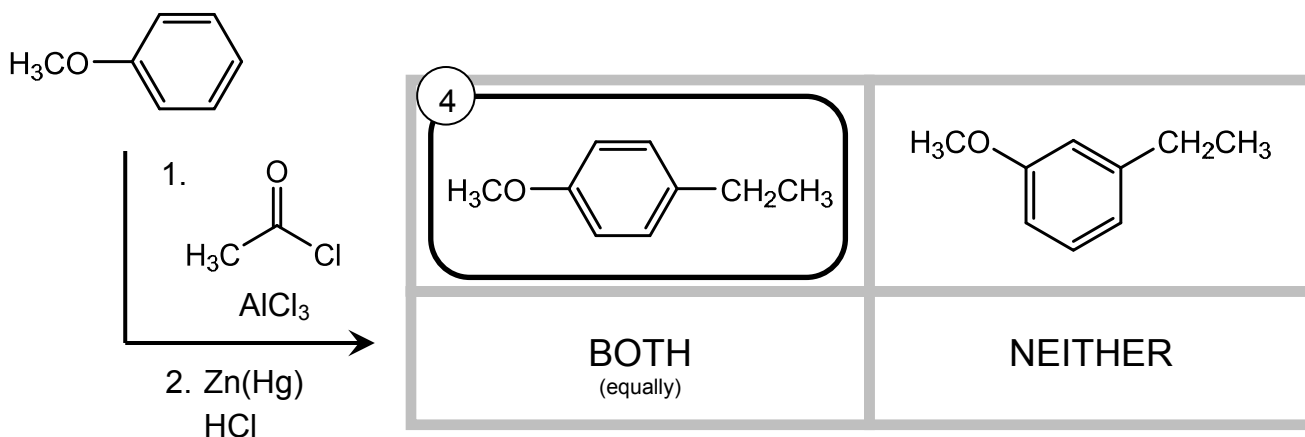
2. (20 pts) Each of the reactions below is drawn with two possible products. If one of the two products predominates, circle that preferred product. If the two products are produced equally, circle "BOTH". If neither product would result from the reaction, circle "NEITHER". **Circle one answer only.**



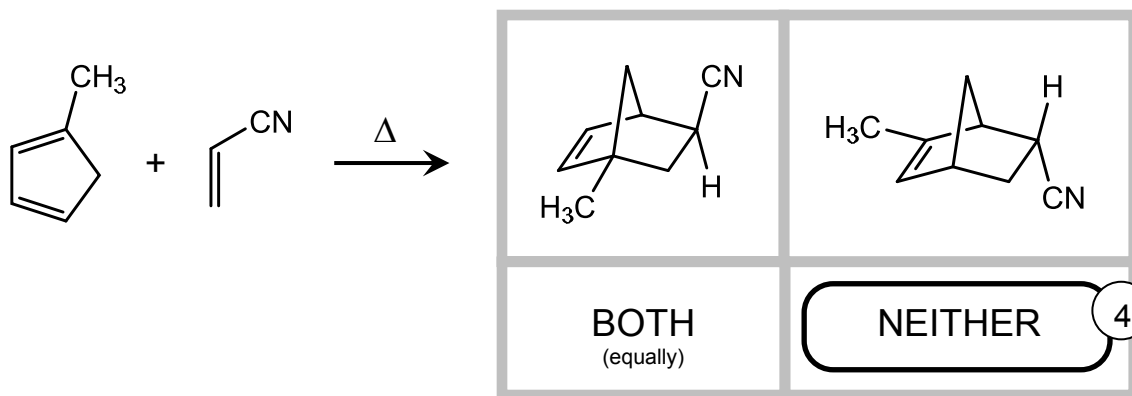
The starting material in this problem is a conjugated diene, and conjugated dienes react with H-Br in a pattern that depends on temperature. At low temperature (and for this reaction, “low” would be $< -40\text{ }^{\circ}\text{C}$), HBr adds via 1,2-addition to yield the kinetic product. At the higher temperature illustrated in this problem, under equilibrating, thermodynamic conditions, HBr adds to generate the most stable, most substituted alkene. In the example that we did in class, the most substituted alkene was generated by 1,4-addition. But here, 1,2-addition generates a trisubstituted alkene (above right), while 1,4-addition makes a disubstituted alkene (above left). So in this problem, both kinetic and thermodynamic conditions create the same product.



Chromate is an extremely strong oxidizing agent, and will oxidize primary alcohols (and aldehydes) all the way to a carboxylic acid.

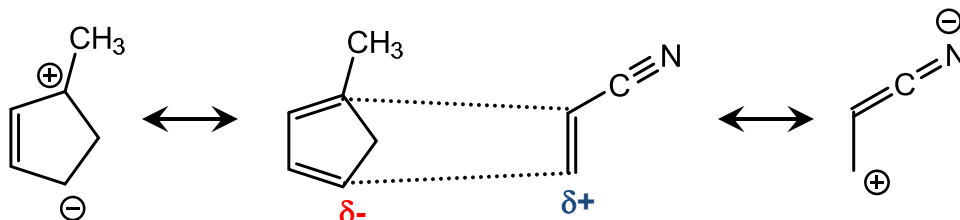


These reaction conditions show a sequence of two reactions: a Friedel-Crafts acylation, which will replace a C-H bond on the benzene ring with a two-carbon acyl group; and a Clemmensen reduction, which will convert the C=O carbonyl in that acyl group to a -CH₂- unit. The initial acylation reaction will be directed by the starting-material substituent, a methoxy group, which is electron-donating. That means the *para*-product should be preferred over the *meta*-product.



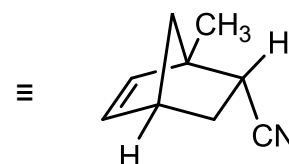
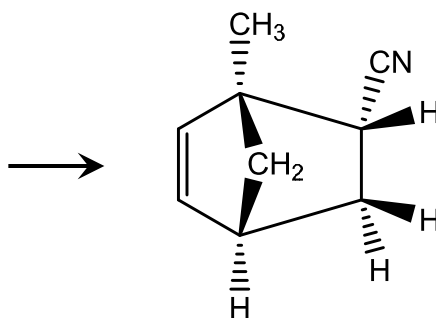
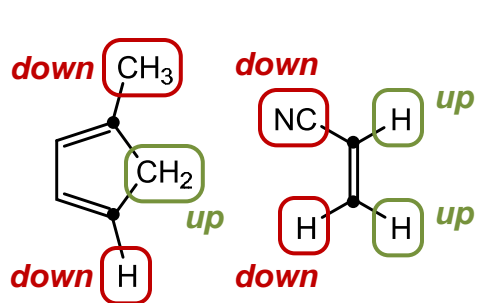
I think there were two ways to answer this problem. The easy way was to rule out both product answers. The first product has its -CN group—a π substituent in the dienophile starting material—*exo*, pointed away from the double bond. It should be *endo*. The second product has the -CN group *endo*, but it has the -CH₃ group attached to the wrong carbon. There is no way for the -CH₃ to be attached to one of the back carbons of the diene side of the molecule. So neither answer can be correct.

But what answer **would** be correct? In order to determine this, we have to evaluate resonance structures in our asymmetric starting materials to find partial charges:



We wouldn't ordinarily consider this a resonance structure. But in Diels-Alder problems, an alkyl group can stabilize a partial positive charge, creating a partial negative on the other end.

Opposites attract, so the approach of the partial charges and the regiochemistry of the reaction will be just like I drew it. But the stereochemistry isn't correct, because I've drawn the -CN group pointed *exo*, or outward. Fixing that:

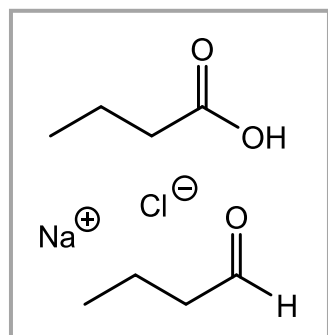


substituents on **right** side of each starting material C point **up** in the product;

substituents on **left** side point **down**

This isn't either of the products drawn in the problem. So the correct answer was "NEITHER".

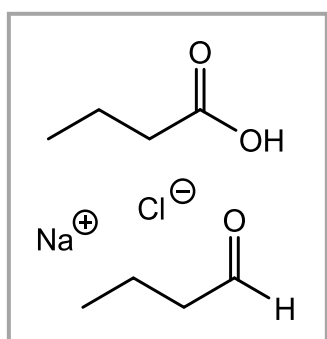
mixture of:



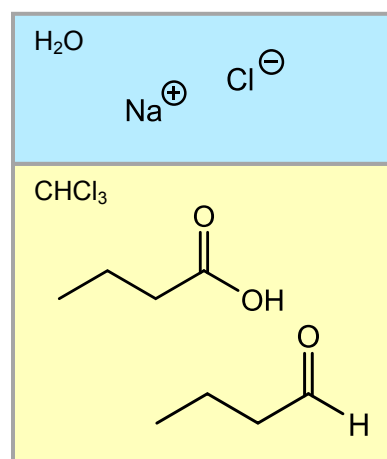
1. Dissolve in a mixture of H₂O and CHCl₃.
2. Discard H₂O layer.
3. Add fresh, basic NaOH/H₂O.
4. Discard H₂O layer.

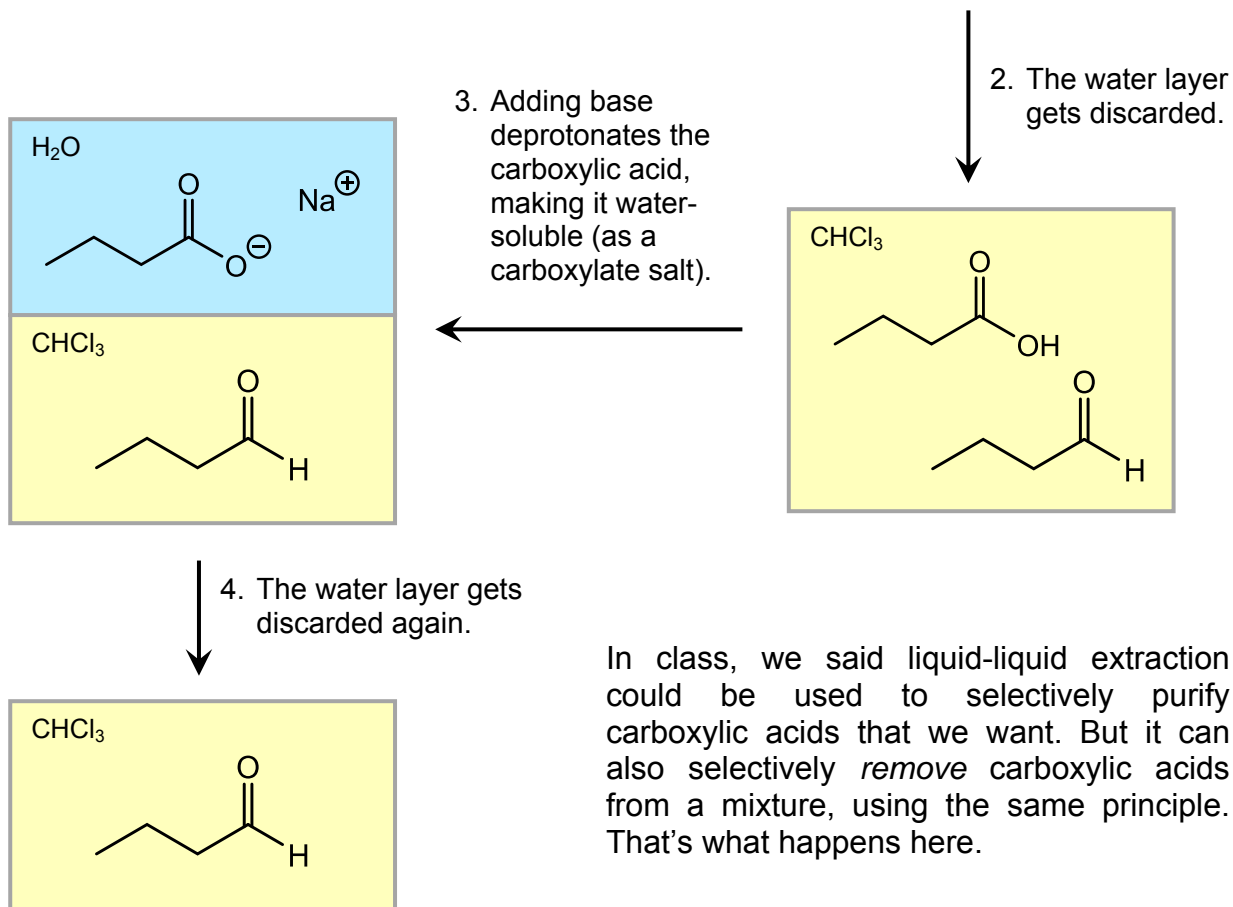
4 	
BOTH (equally)	NEITHER

This problem was kind of like that game where you try to guess which cup the coin is under; your job here is to track the starting molecules through changes in solvent. Here's the sequence of events:

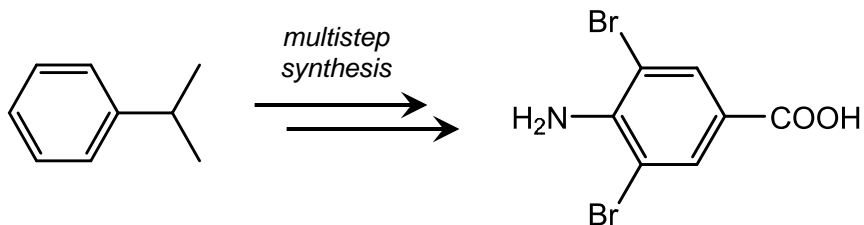


1. Water dissolves the salt, CHCl₃ dissolves the organics.

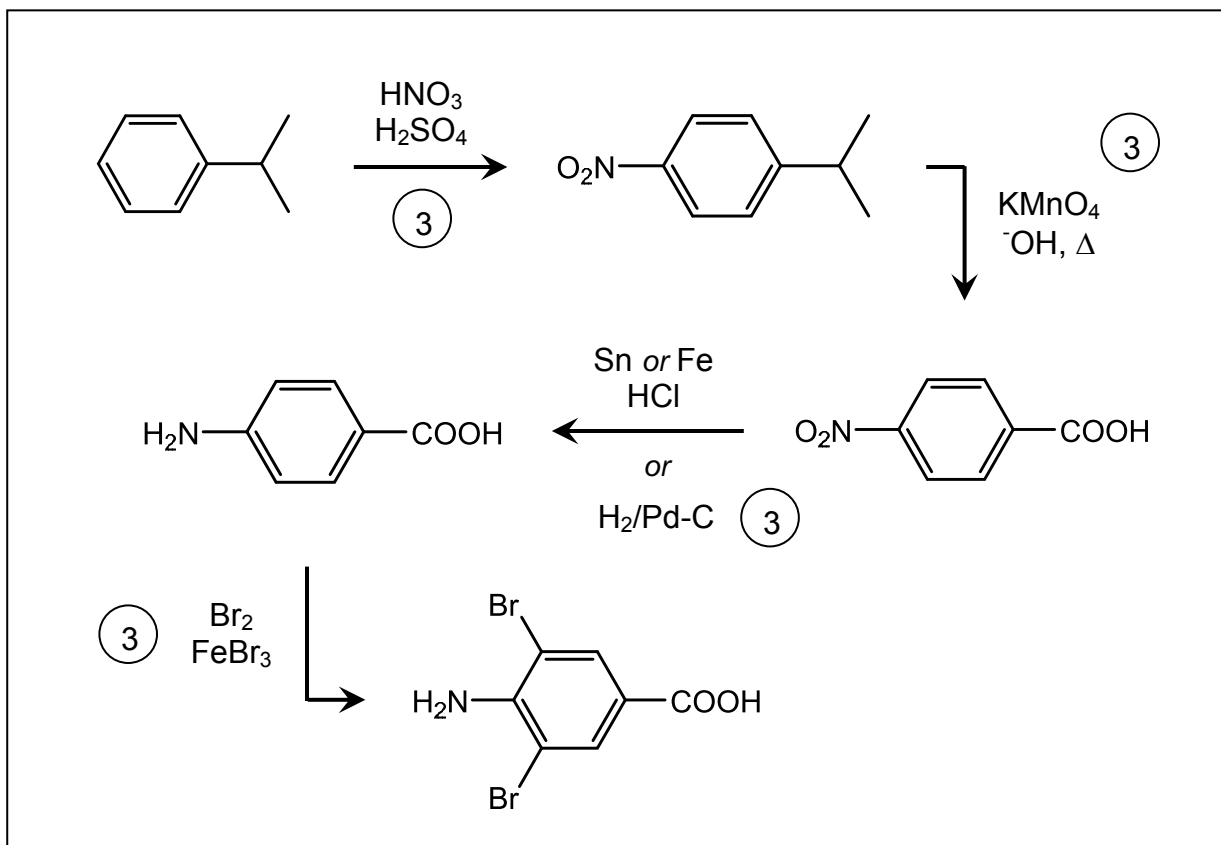




3. (12 pts) On the following page, **propose a multistep synthesis** of the product shown, starting from *meta*-xylene. You may use any reagents and reactions we've learned about in class and/or in the text. You might discover multiple answers to this problem; draw only your best (one) synthetic route. Feel free to draw an incomplete route—we will give you partial credit where we can.



There were quite a few ways to successfully order the required reactions in this synthesis, but there were also ways in which the reaction did not provide the correct regiochemistry. Here's one sample synthesis:



Rubric:

General notes:

Your synthesis was graded on tasks/steps, rather than on molecules. Each task is judged separately, and does not require that the synthesis makes sense, or that other tasks are correct.

If you combined a sequence of successful tasks or reagents into one arrow, without drawing synthetic intermediates, you can still receive full credit for completing the required tasks. *However*, if you do not draw synthetic intermediates, and any of your sequence of tasks is incorrect, you may not receive partial credit for any subsequent steps that are ambiguous to the grader.

-1 point for each *minor, trivial* error in structures or reagents; if error propagates, points are taken off only for initial error.

-2 points if step reagents are incorrect, but reaction could otherwise be accomplished with correct reagents.

-2 points if reagents are correct, but product is wrong. If this happened, and you were led down an incorrect synthetic path by your mistake, you can also lose later points.

We only gave points for reagents if they connected a starting material and a product in an understandable way. So, for example, just writing a change in the starting material, by itself, isn't worth any points.

Tasks:

1. Electrophilic aromatic nitration (3 points).

For full credit, nitration needed to be installed selectively para to the initial group. This won't work, however, if the *iso*-propyl group is oxidized into a *meta*-director first.
1 point partial for nitrating with correct reagents, but incorrect regiochemistry.

2. Oxidize *iso*-propyl group to a -COOH in KMnO₄ (3 points).

This could happen pretty much anywhere.

3. Reduce NH₂ to NO₂ (3 points).

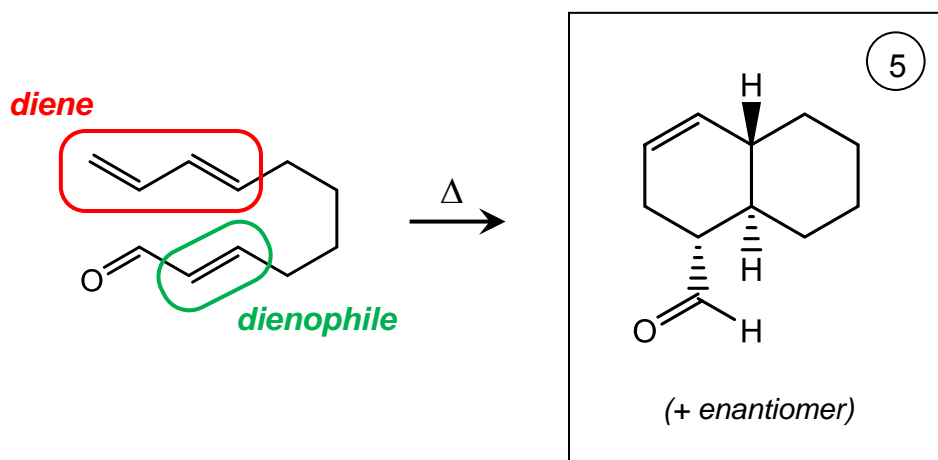
Again, this works at any stage. So, even though I've numbered this step 3 (and the previous one step 2), they could work in just about any order.

4. Electrophilic aromatic halogenation (3 points).

In my synthesis above, the bromines are directed both by the *ortho*-directing -NH₂ group and by the *meta*-directing -COOH. For full credit, your synthesis also needed to direct the bromines correctly.

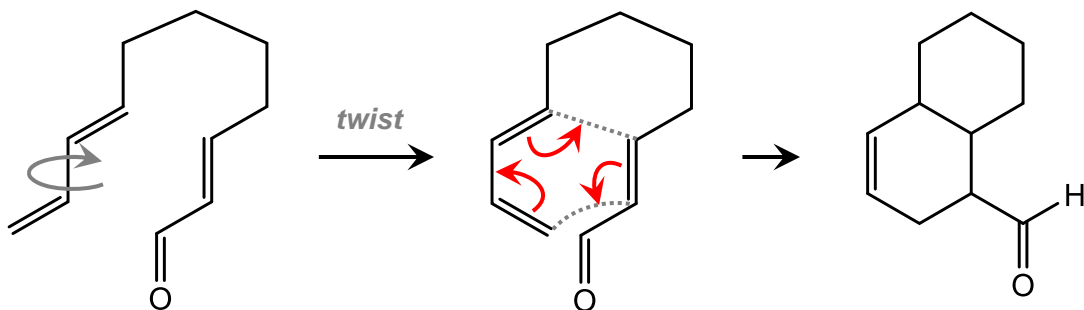
1 point partial for brominating with correct reagents, but incorrect regiochemistry.

4. (23 pts) For each of the reactions below, fill in the empty box corresponding to reactants or products. Give only one answer in each box. For reactions that you expect to yield multiple products, give the major product. For reactions that yield multiple enantiomers, draw only one enantiomer in the box, and include the note "+ enantiomer".

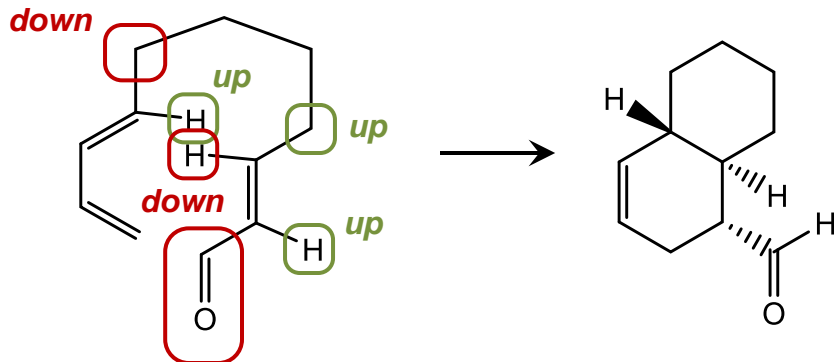


This problem illustrated an intramolecular Diels-Alder reaction—a reaction in which the diene and the dienophile are attached to the same molecule. We solve this problem just like any other Diels-Alder problem. We line up the diene and dienophile in their reactive conformations, make new bonds, and evaluate stereochemistry.

The first problem here is that our diene is *s-trans*, but needs to be *s-cis* to react. We'll need to twist the central single bond first:



That illustrates the overall shape of the product molecule. But what about stereochemistry? At the carbon atoms that form new bonds, each group pointed leftwards ends up down in the product, and each group pointed right ends upwards. Applying that to the reactive conformation above,



Rubric for this part:

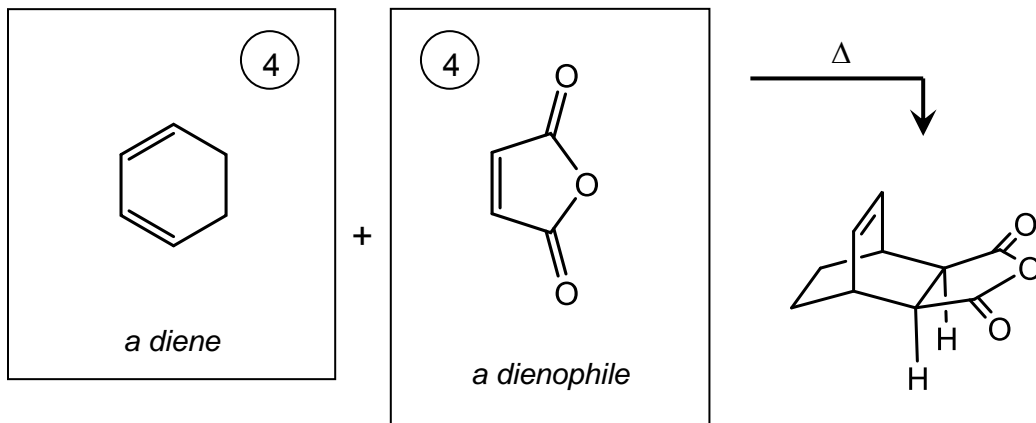
5 points for correct structure above (or its enantiomer, w/ opposite stereochem. at all locations).

4 points partial for correct answer, but omitting "+ enantiomer".

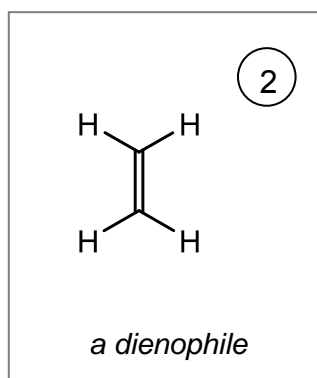
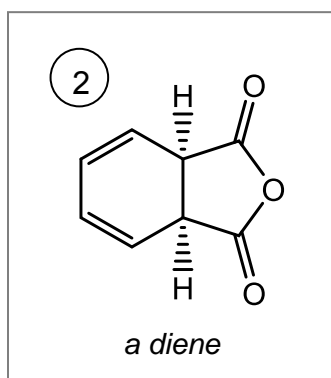
3 points partial for correct answer, but incorrect/unclear relative stereochemistry.

1 point partial for any [6,6]-bicyclic molecule with the Diels-Alder double bond in the right place.

-2 points for each clearly trivial structure mistake. (E.g., omitting double bond in ring.) By "trivial", I mean your intent must be clear—it must be obvious that you meant to write the correct answer, but you accidentally made a minor change that keeps your intent clear.



OR



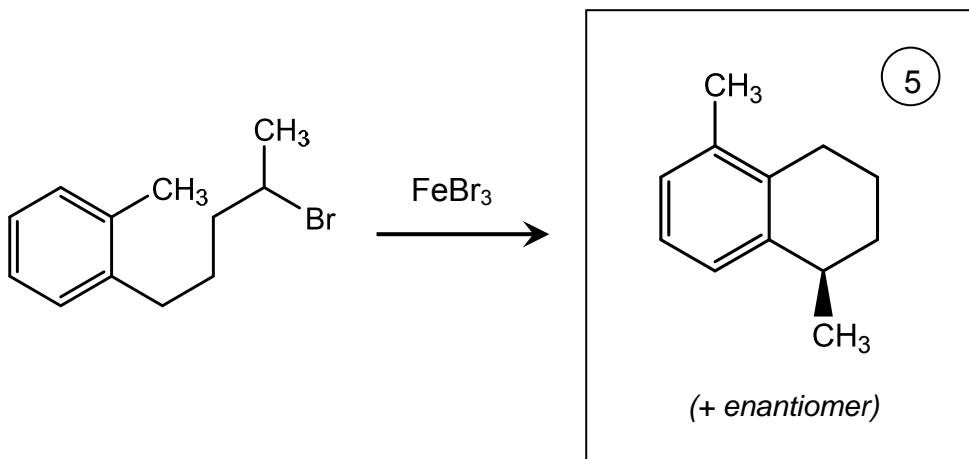
This combination isn't as good, because the dienophile (ethylene) isn't activated by an electron-withdrawing group.

Rubric for this part:

4 points for each correct structure.

-2 points each if dienophile and diene components are switched (if you put the diene in the dienophile box and vice versa).

-2 points for each clearly trivial structure mistake.

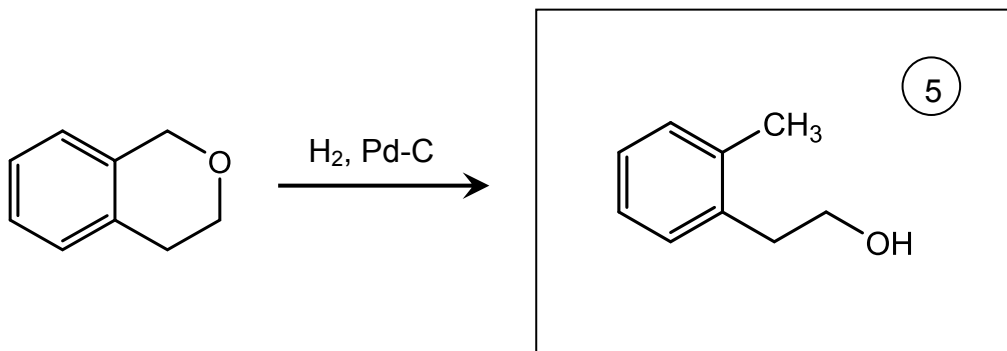


Rubric for this part:

5 points for correct structure.

2 points partial for other, incorrect intramolecular ring closure. (This includes adding alkyl group at methyl position.)

-2 points for each clearly trivial structure mistake.

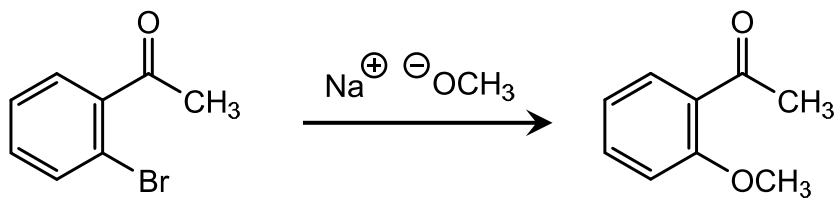


Rubric for this part:

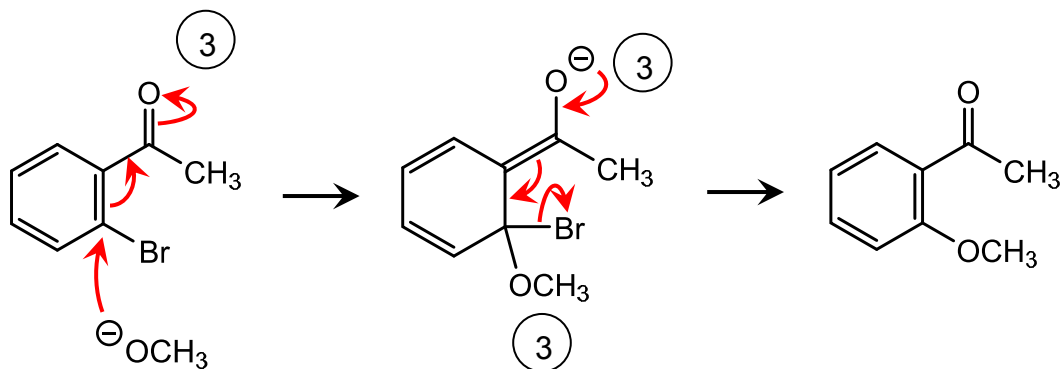
5 points for correct structure.

-2 points for each clearly trivial structure mistake, including incorrect number of carbons in alkyl chain.

5. (9 pts) **Draw a mechanism** (using “electron pushing”) for each of the reaction shown below. Draw each mechanistic step explicitly; don’t cheat by combining multiple processes in a single step. Use only the molecules shown in the problem; don’t invoke generic species. (E.g., don’t use “B:” as a generic base.)



Mechanism:



This was a nucleophilic aromatic substitution reaction. As we discussed in class (and Smith describes in the text), the mechanism of this reaction is different from the $\text{S}_{\text{N}}1$ and $\text{S}_{\text{N}}2$ substitutions you learned about in OChem I in that the nucleophile adds first, and then the leaving group leaves second.

Rubric:

3 points for each electron-pushing step.

3 points for intermediate anion.

Overall notes:

Overall, the minimum score for each step is zero; errors in a step cannot earn you negative points that count against another, correct step.

Things that have left for good (e.g., Br^-) and spectators (e.g., Na^+) may be omitted.

Resonance is NOT a mechanistic step; it is just multiple ways of drawing the same intermediate. As a result, we did not evaluate electron-pushing that showed resonance—you can push electrons for resonance, or not, your choice. Any molecule can be represented in any resonance form; in particular, there were a number of ways that you could have drawn the intermediate. In

addition, resonance does not have to be shown as an explicit “step”—it can be combined with adjacent steps, for full credit.

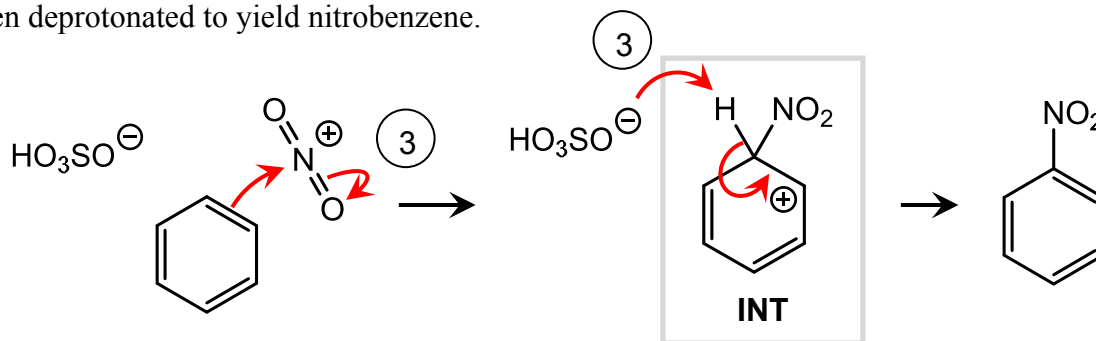
-2 points, for each arrow in each step, for errors in drawing arrows. Arrow must start at an electron pair, and end at nucleus or bond where electrons will newly interact. Can only lose points if you get them.

-1 point for each minor error in charge, valency, structure, etc.; if error propagates, points are taken off only for initial error.

-2 points for each use of a generic or incorrect nucleophile/base. For example, in the last step you couldn't invoke OH^- or any other base you may have used in other problems.

If you combined the two steps into an $\text{S}_{\text{N}}2$ reaction (or something similar), you can get points for arrows that are in the rubric, but not for the intermediate you skipped.

6. (24 pts) When benzene is subjected to electrophilic aromatic nitration in a mixture of H_2SO_4 and HNO_3 , it adds NO_2 to form the conjugated cation intermediate **INT** drawn below. **INT** is then deprotonated to yield nitrobenzene.



- a. Draw the mechanism of both steps of this reaction, using “electron pushing”, by adding curved arrows to the structures above.

Rubric for electron pushing:

3 points for each electron-pushing step.

-2 points, for each arrow in each step, for errors in drawing arrows. Arrow must start at an electron pair, and end at nucleus or bond where electrons will newly interact. Can only lose points if you get them.

- b. Is **INT**

AROMATIC,

ANTIAROMATIC,

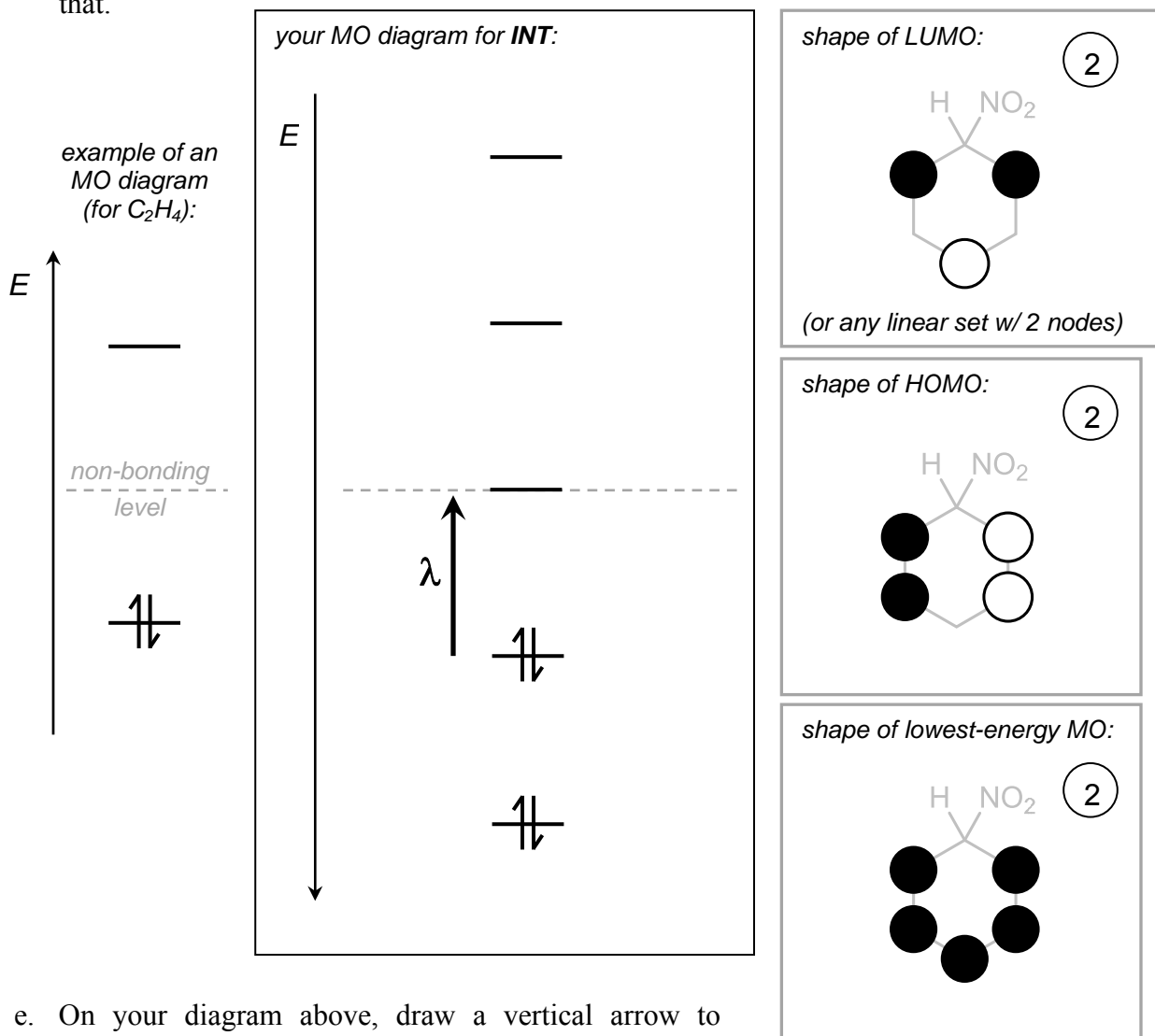
or

NON-AROMATIC

?

INT has an sp^3 -hybridized carbon at the top. As a result, it does not have a complete cycle of p orbitals, so it can't be aromatic or anti-aromatic.

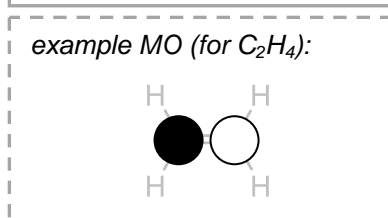
- c. On the energy diagram below, **draw a molecular orbital (MO) diagram** for the conjugated π orbitals in the ring.
- Draw all orbital energy levels as horizontal lines;
 - Fill your orbitals with the appropriate number of electrons.
- d. In the boxes on the right, draw the shapes of INT's LUMO, HOMO, and lowest-energy molecular orbital as combinations of atomic orbital lobes, viewed from the top of the molecule. If there is more than one LUMO, HOMO or lowest-energy orbital, just draw one. I have drawn the molecule's backbone in each box; draw each orbital right on top of that.



- e. On your diagram above, draw a vertical arrow to illustrate an electronic transition that could be observed as an absorption peak in the UV/vis spectrum of INT. Label the arrow " λ ".

3 for 5 MOs, in any order.

2 for arranging these orbitals vertically (for a linear combination of p orbitals).



- ② *for filling orbitals with a total of 4 electrons.*
- ③ *for drawing an arrow from HOMO to LUMO.*