

CHEM 347 – Organic Chemistry II – Spring 2015

Instructor: Paul Bracher

Hour Examination #1

Wednesday, February 11th, 2015

6:00–8:00 p.m. in Macelwane Hall 334

Student Name (Printed)	Solutions
Student Signature	N/A

Instructions & Scoring

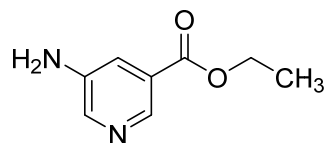
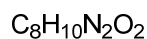
- Please write your answers on the official answer sheet. No answers marked in this booklet will be graded.
- Please write your name on the front *and* back of the answer sheet.
- You may use one letter-sized sheet of hand-written notes and your plastic model kit. No electronic resources are permitted and you may not communicate with others.
- Your exam answer sheet may be photocopied.

Problem	Points Earned	Points Available
I		30
II		18
III		12
IV		20
V		20
TOTAL		100

Questions, **Required Information**, **Supplementary Information**

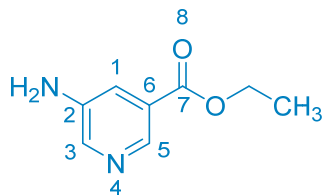
Problem I. Multiple choice (30 points total; +5 points for a correct answer, +2 points for an answer intentionally left blank, and 0 points for an incorrect answer). For each question, select the best answer of the choices given. Write the answer, legibly, in the space provided on the answer sheet.

- (1) B How many atoms in compound **A** are sp^2 -hybridized?

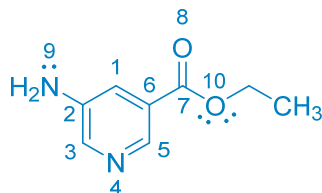
**A**

- (a) 9
 (b) 10
 (c) 11
 (d) 12
 (e) all of the atoms in **A** are sp^2 -hybridized

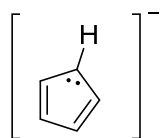
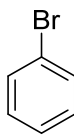
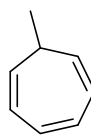
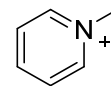
Recall from first semester that an atom will be sp^2 -hybridized when it is connected to three groups (i.e., structural pairs = atoms + lone e^- pairs). There are 8 such atoms in **A**:



Subsequently, we learned that atoms that we might “normally” consider sp^3 -hybridized because they have four structural pairs will adopt sp^2 hybridization if they are adjacent to a π system and have at least one lone e^- pair that can occupy an unhybridized p orbital and participate in favorable interactions with the π system. Essentially, the energetic cost of adopting a less-spatially favorable arrangement of groups is more than paid back by the ability of the lone pair to participate in conjugation with the adjacent π system. There are 2 more of these atoms in **A**, for a total of 10 sp^2 -hybridized atoms:



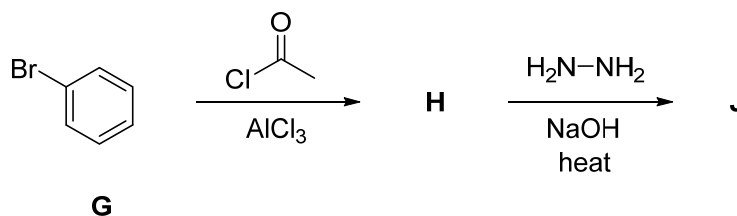
(2) D How many of the following compounds are aromatic?

**B****C****D****E****F**

- (a) one
- (b) two
- (c) three
- (d) four
- (e) five

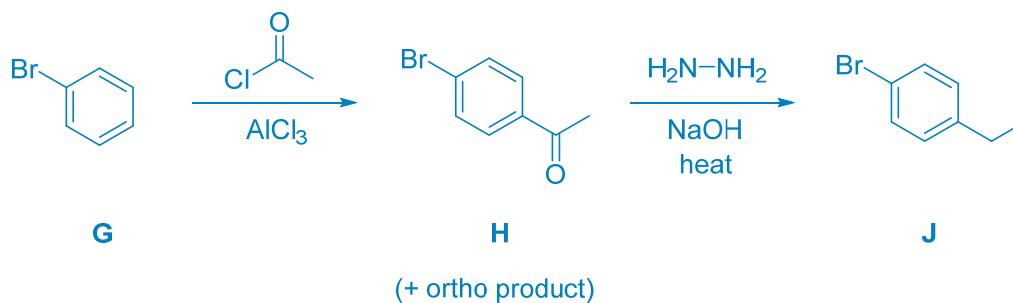
A compound is aromatic if it has a planar ring with an uninterrupted sequence of unhybridized p orbitals that collectively hold $4n+2$ electrons where n is a whole number. Compound **B**—the cyclopentadienyl anion—is aromatic (6 π electrons, 4 in two π bonds and 2 in a lone pair in a p orbital). Compound **C** is aromatic (6 π electrons, 6 in three π bonds). Compound **D** is not aromatic since an sp^3 carbon in the ring interrupts the conjugation of the π system so the overlapping p orbitals don't form a complete ring. Compound **E**—pyridine—is aromatic (6 π electrons, 6 in three π bonds). Note that the lone pair is in an sp^2 -hybridized orbital that is orthogonal to the p orbitals in the ring, so these two electrons do not “count” as far as aromaticity is concerned. Compound **F** is aromatic (6 π electrons, 6 in three π bonds). Note there is essentially no difference from **E** (in terms of aromaticity) because the two electrons used to form the additional bond to carbon use those two electrons that were in the orbital orthogonal to the ring system in **E**.

(3) A What is the name of the major product (**J**) expected of the following sequence of reactions?



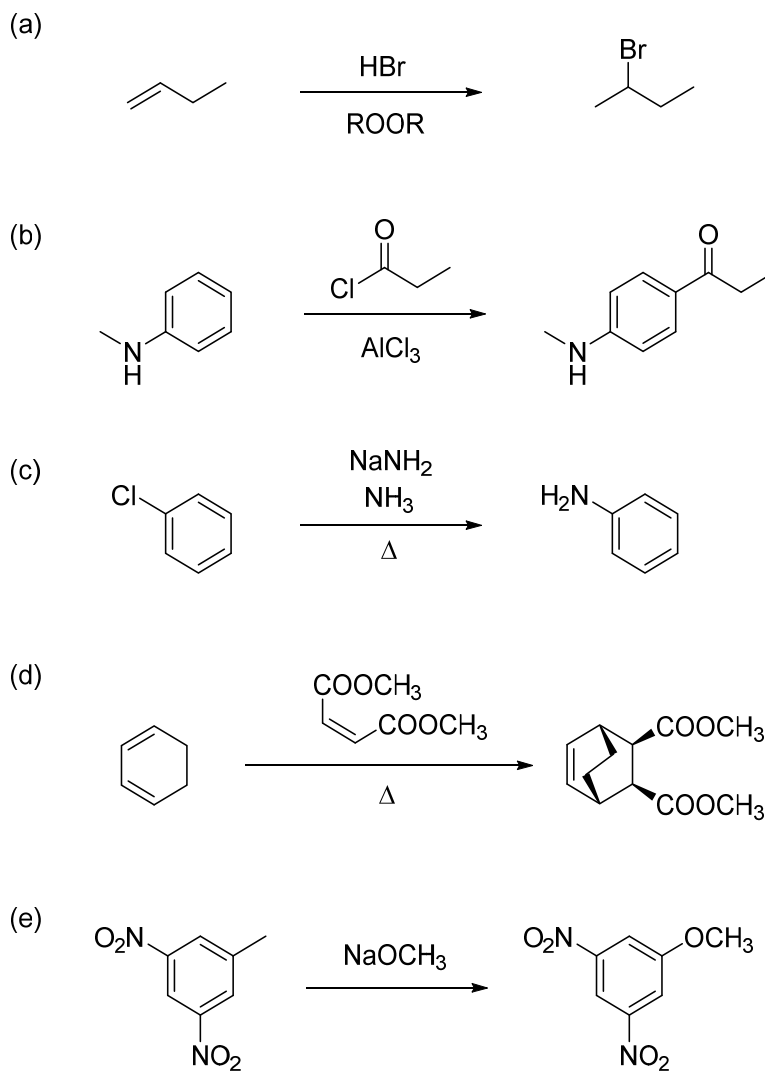
- (a) 1-bromo-4-ethylbenzene
- (b) *m*-bromotoluene
- (c) *p*-bromotoluene
- (d) *m*-bromobenzoic acid
- (e) *p*-bromobenzoic acid

The expected sequence of reactions is:



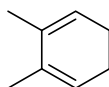
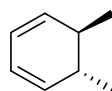
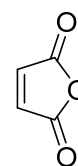
Compound **J** is named 1-bromo-4-ethylbenzene.

- (4) **C** Which of the following reactions is not flawed and will produce the major product as shown?



Only reaction (c) will proceed as drawn (by elimination of HCl to form benzyne, which is subsequently attacked by ammonia). In reaction (a), HBr will add by a radical mechanism to form 1-bromobutane, not 2-bromobutane. In reaction (b), the amine will complex with the Lewis acid catalyst to deactivate the ring and poison the catalyst. In reaction (d), the exo Diels–Alder product is drawn although the endo product should be major. In reaction (e), the methyl group is a woeful leaving group and cannot be displaced as drawn by nucleophilic aromatic substitution.

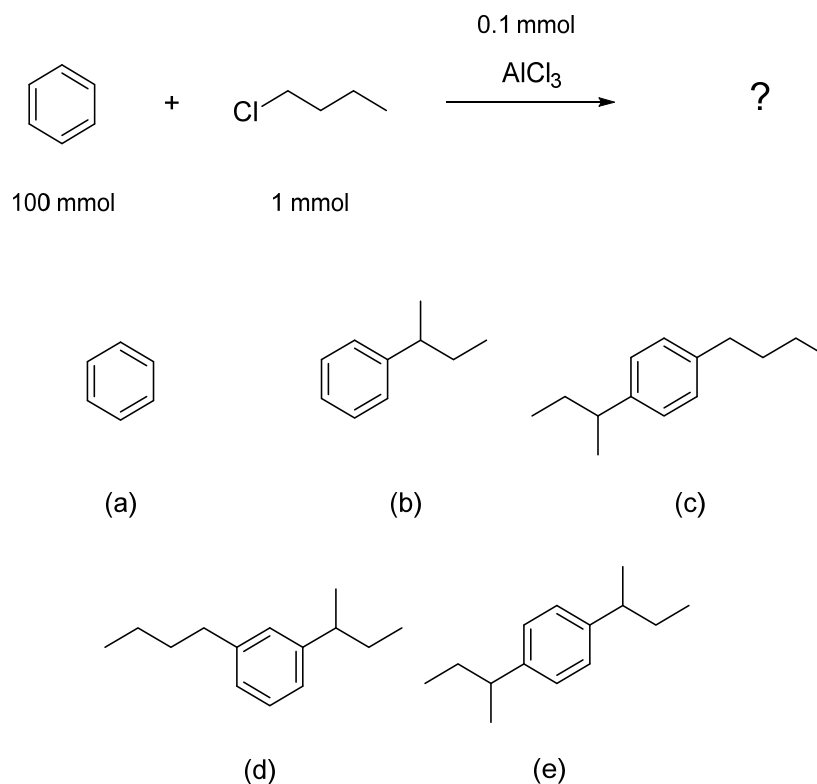
(5) **B** Which of the following statements is not correct?

**K****L****M**

- (a) compound **K** is named 2,3-dimethyl-1,3-cyclohexadiene
- (b) compound **L** has a less exothermic heat of hydrogenation than **K**
- (c) compound **K** will react faster than **L** with compound **M**
- (d) compound **K** will react with **M** to form a new six-membered ring
- (e) the major product when HBr is added to **K** will vary as a function of temperature

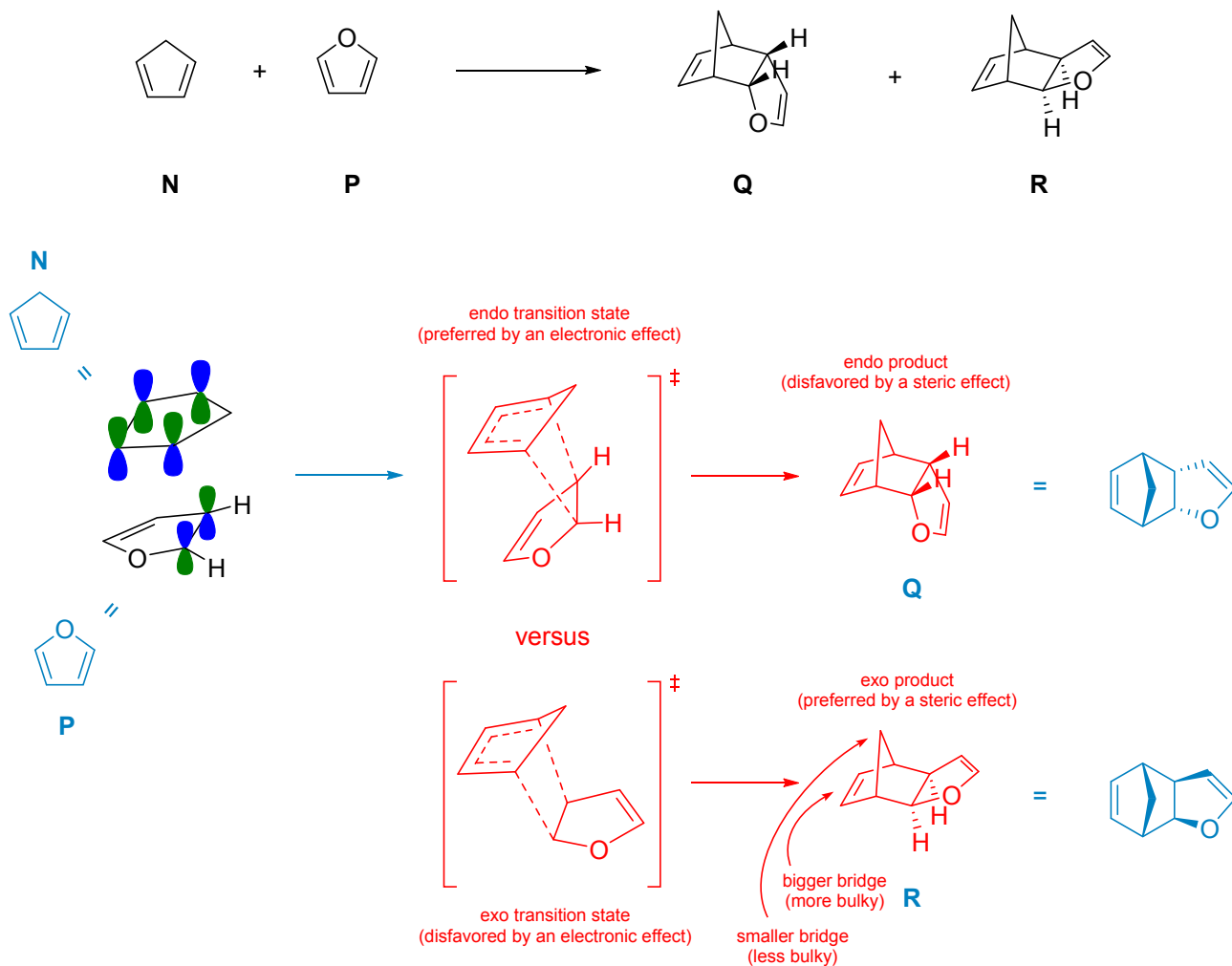
It's best to evaluate each statement independently. For statement (a), the given name is correct for compound **K**. For statement (b), while both **K** and **L** are isomeric dienes that are hydrogenated to the same product, we expect the process to be less exothermic for **K** because its π bonds have a greater substitution by alkyl groups, and hence, are more stable. Thus, statement (b) is incorrect. Statement (c) is correct, as we do expect **K** to react faster than **L** with **M** in a Diels–Alder reaction because **M** is an electron-deficient dieneophile substituted with electron-withdrawing groups and will react faster with electron-rich dienes. **K** is more electron-rich than **L** because the π system of **K** is substituted with more alkyl groups, which are electron donors. Statement (d) is correct, as **K** and **M** will react by a Diels–Alder reaction to form a new six-membered ring. Statement (e) is correct, as **K** is a diene that will give products of variable stability based on 1,2- vs. 1,4-addition of HBr that are subject to kinetic vs. thermodynamic control.

- (6) D Which of the following compounds would you expect to find in the lowest concentration when excess benzene is treated with 1-chlorobutane and aluminum trichloride?



Product (d) is especially unlikely to form. In Friedel–Crafts alkylation reactions, primary alkyl halides often generate secondary or tertiary carbocations (following complexation with AlCl_3 and rearrangement). In this case, it is more likely for the ring to be alkylated as a *sec*-butyl group rather than an *n*-butyl group. Furthermore, once one alkyl group has added, the next addition will be preferentially directed to an *ortho* or *para* position. In product (d), the two alkyl groups have a *meta* relationship, and one of them is *n*-butyl.

Problem II. Explanation (18 points). Cyclopentadiene (**N**) and furan (**P**) react to form diastereomers **Q** and **R** by the Diels–Alder reaction.



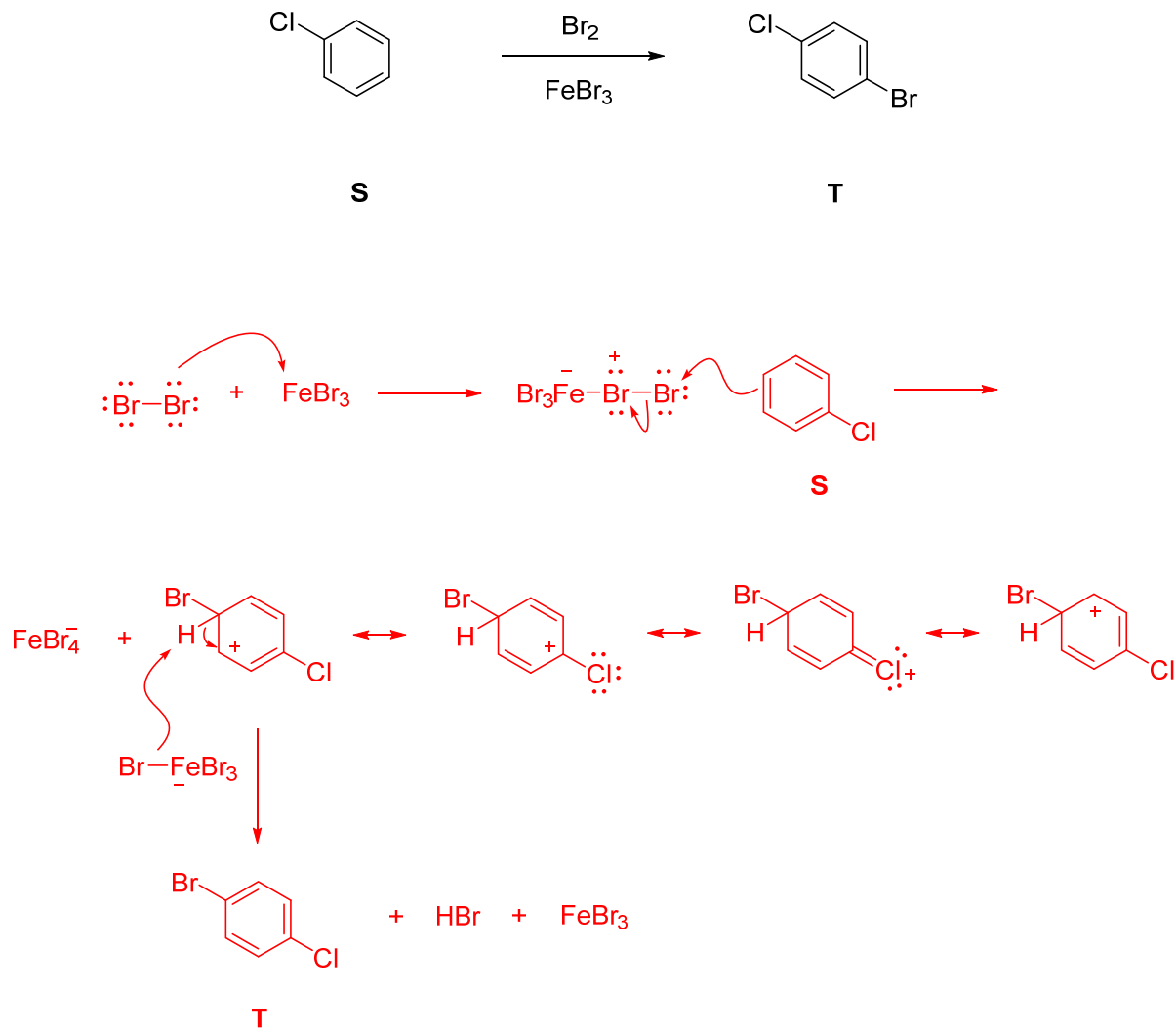
Part (1). (9 points) Explain why product **Q** is favored at lower temperatures and shorter reaction times.

Product **Q** is favored at lower temperatures because it is formed by a more-stable transition state than that for **R**. **Q** is formed by the endo transition state, where secondary orbital interactions lower the activation energy and result in a faster reaction. **Q** is the kinetic product, formed at lower temperatures and shorter reaction times.

Part (2). (9 points) Explain why product **R** is favored at higher temperatures and longer reaction times. Hint: Do both sides/faces of the double bond look the same?

Product **R** is favored at higher temperatures and longer reaction times because it is itself more stable than **Q**. **Q** is the thermodynamic product. While **R** is formed slower—since it is made via a higher-energy transition state—the Diels–Alder reaction is reversible, and at higher temperatures and longer reaction times, the system can reach (or get closer to) equilibrium. Equilibrium favors the overall most-thermodynamically-stable product. Here, that is **R** (the exo product), since the ring of the dieneophile (which is bulkier than hydrogens of the dieneophile) is placed on the side of the diene with the smaller (less bulky) bridge (one carbon vs. two carbons).

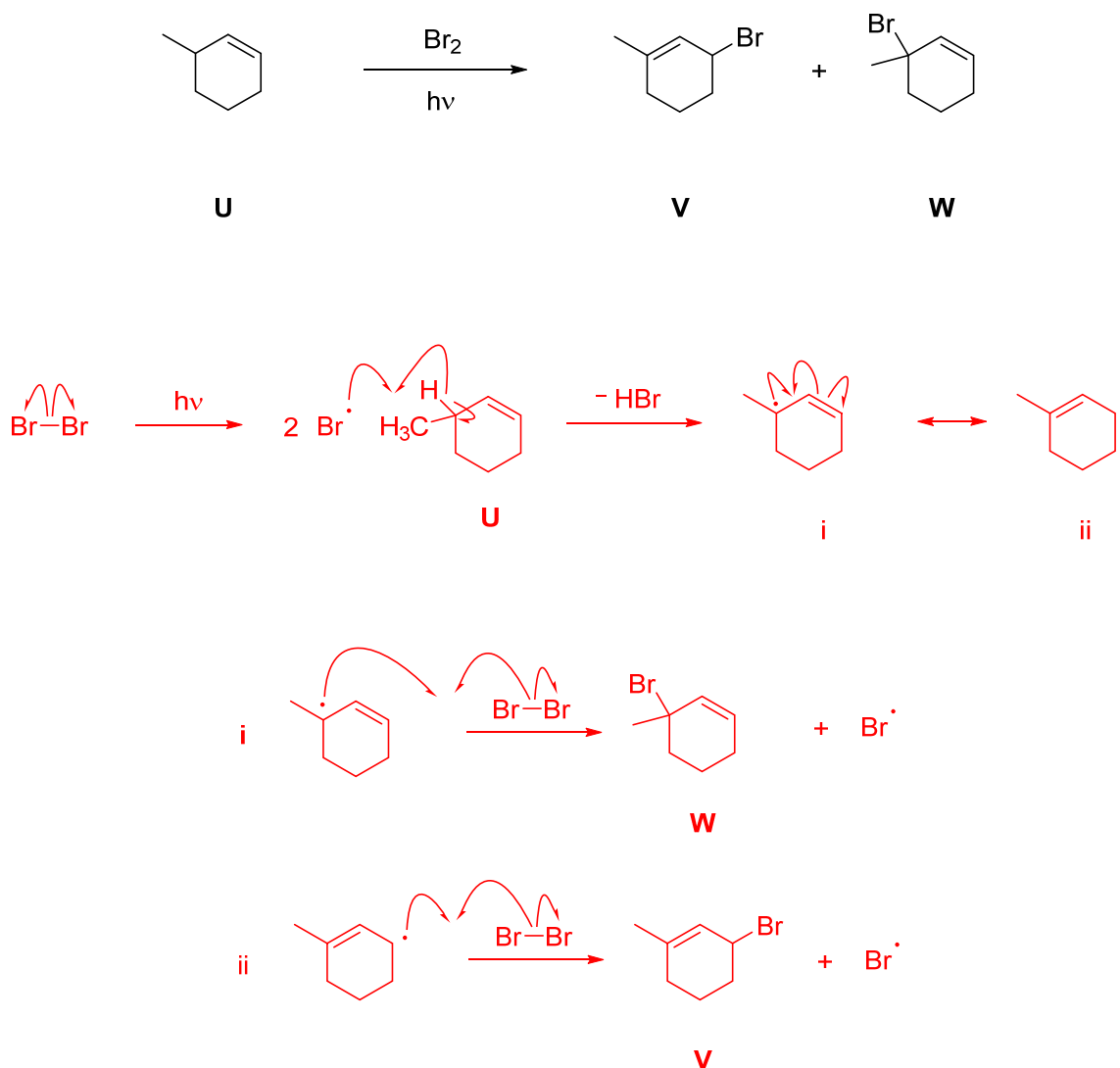
Problem III. Mechanism (12 points). Draw a sensible mechanism for the formation of **T** in the reaction drawn below. Remember to use proper “curved arrow notation” to account for the redistribution of electrons in the making and breaking of bonds. Show all significant resonance forms that account for the stability of the intermediates in the reactions.



This is a run-of-the-mill electrophilic aromatic substitution reaction. The chloro group is *ortho/para* directing. Note there are four key resonance forms for the cationic intermediate, which includes one form in which a lone pair from a $3p$ orbital is pushed onto the electron-deficient ring.

Problem IV. Mechanism (20 points).

Part (1) (14 points). Draw sensible mechanisms for the formation of **V** and **W** when **U** is irradiated with light in the presence of one equivalent of bromine. Remember to use proper “curved arrow notation” to account for the redistribution of electrons in the making and breaking of bonds. Show all significant resonance forms that account for the stability of the intermediates in the reactions.

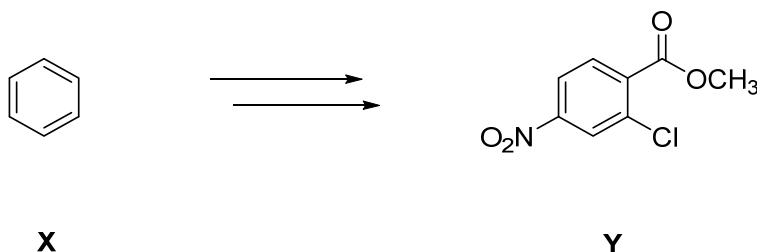


Part (2) (6 points). Which of these products, **V** or **W**, would you expect to predominate as the major product, especially as the temperature of the reaction is raised? Briefly explain.

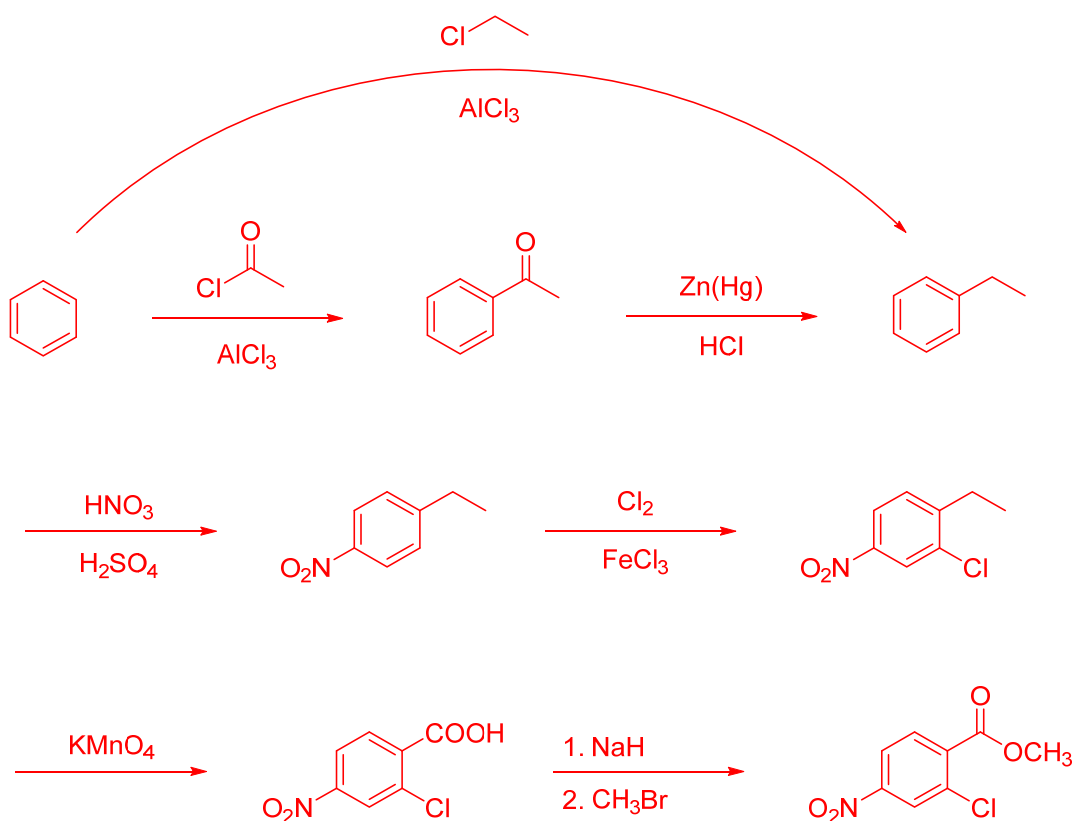
Compound **V** should be produced in higher yield because it is more stable, as the alkene has greater alkyl substitution.

Note added in proof: Even if the radical reaction did not favor **V**, **W** and **V** could interconvert by an $\text{S}_{\text{N}}1$ reaction.

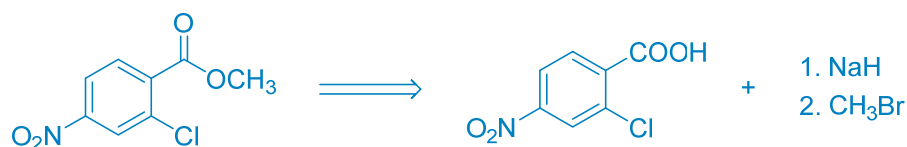
Problem V. Synthesis (20 points). Provide a synthetic route—i.e, a sequence of reactions—to produce compound **Y** from benzene (**X**) and any other reagents you need. Hint: Remember from last semester that methyl esters (RCOOCH_3) can be made from substitution reactions of methyl halides (e.g., CH_3Br).



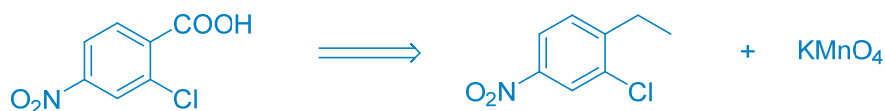
(use excess benzene to minimize overalkylation)



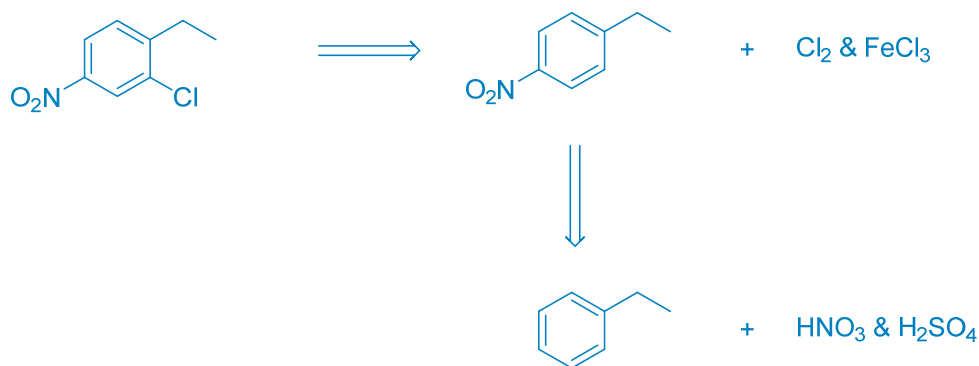
There is a lot going on here in terms of getting from the starting material to the product. That, and the fact that the starting material is a blank slate, suggests that a backwards approach to solving this problem is best. Furthermore, in the prompt to the question, you are given a big hint about the final step: methyl esters can be prepared by $\text{S}_{\text{N}}2$ reactions of CH_3Br . What is the other reagent needed? A carboxylate (a deprotonated carboxylic acid)...



Now we need to decide the order of installation of the groups on the ring. When we look at the benzoic acid intermediate, we note that the carboxyl group (a *meta* director) is *para* and *ortho* to the other substituents. Furthermore, the only way we currently know to install an aryl carboxylic acid group is by oxidation of alkyl groups. Thus, the following retrosynthetic idea is worthy of trying:



Note that here an ethyl group is shown, but it could be any alkyl group so long as it has at least one (benzylic) hydrogen on the carbon attached to the ring. We can now see that the alkyl group is *ortho* and *para* to the two other substituents, which is good, because alkyl groups are *ortho/para* directing. It makes sense that the alkyl group might be the first substituent installed. In deciding whether to install the nitro or chloro group first, we should note that they have a *meta* relationship and that nitro groups are *meta* directing while chloro groups are *ortho/para* directing. Thus, it makes sense to try installing the nitro group before the chloro group. The reactions for this sequence are straightforward:



Finally, we can work forwards rather than backwards. We can get from benzene (your given starting material) to ethylbenzene quite easily by a Friedel–Crafts alkylation (using benzene in vast excess to avoid over-alkylation, as the ethylbenzene product is more activated than the benzene starting material). Alternately, we can use Friedel–Crafts acylation followed by reduction of the carbonyl group. Clemmensen reduction (shown on the previous page, zinc amalgam in acid) and the Wolff–Kishner reduction (hydrazine, followed by heating with strong base) are the classic choices.