

# Chemistry 261: Organic Chemistry

## Examination #2

October 14, 2013

Name: ANSWER KEY

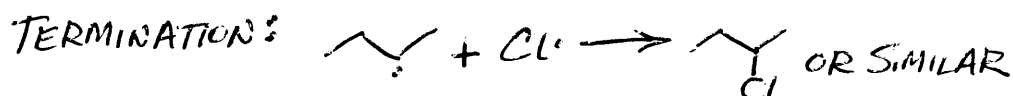
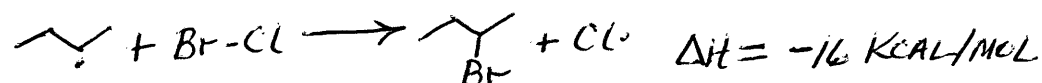
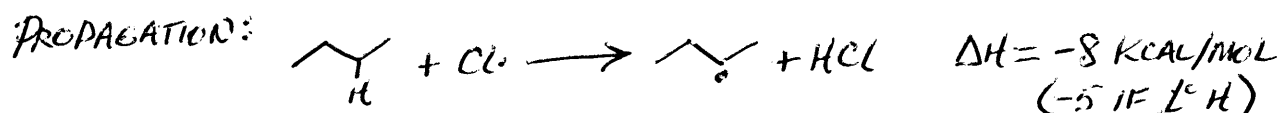
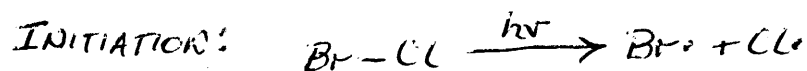
Student ID Number:

Exams will be returned via the Chem 261 wall-mount racks outside Lab Sci 300.

Please check the box if you would prefer to pick up your graded examination directly from Prof. Ponder during office hours.

**Problem 1 (12 points; A = 7 points, B = 5 points)** Bromine chloride (BrCl) is a caustic yellow gas with a bond length of 2.14 Å and bond energy of 52 kcal/mol, values almost exactly intermediate between those for chlorine (Cl<sub>2</sub>) and bromine (Br<sub>2</sub>).

(A) Write a complete mechanism, including initiation, propagation and termination steps, for the reaction of bromine chloride with butane. Estimate the heat of reaction for the individual propagation steps and the overall mechanism.



OVERALL  $\Delta H = -8 + (-16)$

(+1) FOR EACH OF THE 4 REACTIONS

$= -24 \text{ kcal/mol}$

(+1) FOR EACH OF THE 3  $\Delta H$  VALUES

(-21 if 1° H)

(B) We have discussed the relative selectivity of reactions of alkanes with chlorine and bromine. What do you expect for the selectivity of the BrCl reaction? Explain.

(+2) FIRST PROPAGATION STEP IS H-ABSTRACTION BY Cl· (NOT Br·) SINCE Cl· REACTION IS EXOTHERMIC, AND THUS MORE FAVORABLE

(+3) THE OVERALL REACTION IS BROMINATION OF BUTANE. BUT THE 2°/1° PRODUCT RATIO WILL BE THAT OF CHLORINATION ("LESS SELECTIVE") SINCE THE PRODUCT RATIO IS DETERMINED BY THE FIRST PROPAGATION STEP (LESS SELECTIVE ABSTRACTION BY Cl·)

**Problem 2 (10 points; A & C = 4 points each, B = 2 points)** All of the alkyl bromides shown below react with lithium iodide (LiI) in acetone at 25°C. The relative reaction rates (assuming EtBr = 1) are given. Note Boltzmann's constant ( $k$ ) is  $1.38 \times 10^{-23} \text{ JK}^{-1}$ , and the gas constant ( $R$ ) is 1.987 cal/mol/K.

	neo-Pentyl Bromide	iso-Butyl Bromide	n-Propyl Bromide	Ethyl Bromide
Relative Rate =	0.00002	0.036	0.8	1

(A) Calculate the difference in activation energy for the reaction of ethyl bromide vs. neo-pentyl bromide.

$$R_{\text{NEO}}/R_{\text{ET}} = 0.00002 = e^{-\Delta E_a/RT},$$

$$\text{THEN } \Delta E_a = -RT \ln(0.00002) = 6.4 \text{ KCAL/MOL}$$

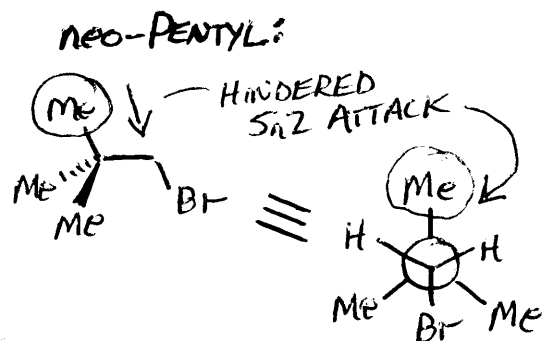
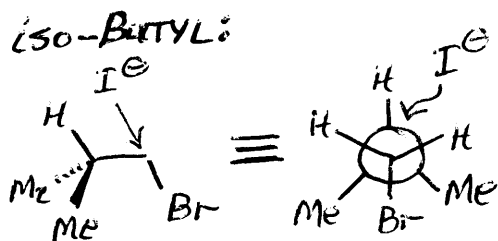
(+2) RATIO VERSION OF ARRHENIUS EQUATION

(+2) CORRECT NUMERICAL ANSWER

(B) How will the relative rates change if the concentration of LiI is doubled?

(+2) RELATIVE RATES WILL NOT CHANGE

(C) Why does iso-butyl bromide react 1800× faster than neo-pentyl bromide, but only 22× slower than n-propyl bromide. Use pseudo-3D drawings and/or Newman projections to illustrate your answer. [Note: The bromides on the left are obviously more "crowded" than those on the right. We are looking for a more detailed, specific explanation of the large difference between 22× and 1800×.]

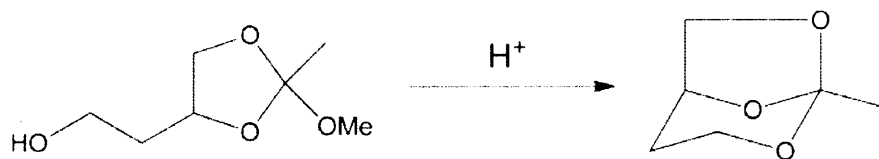


(+2) PROPER NEWMAN PROJECTION

(+2) EXPLANATION

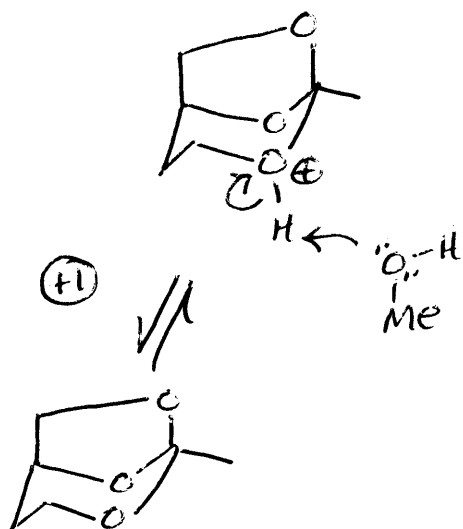
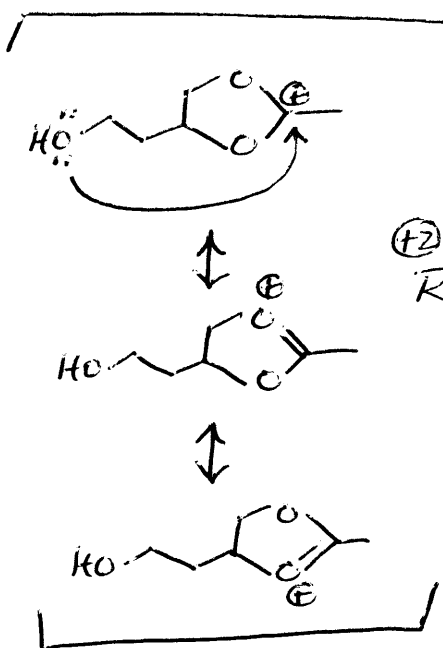
**Problem 3 (10 points)**

Write a detailed reaction mechanism for the acid-catalyzed transformation shown below. Be sure to show all steps, including proton transfers. Use curved arrows to indicate the flow of electrons, and include all reasonable resonance structures.



- (1) FOR EACH MISSING FORMAL CHARGE
- MAX OF (3) FOR S<sub>N</sub>2

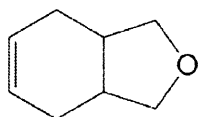
✓ (3)



**Problem 4 (10 points; A = 4 points, B & C = 3 points each)**

(A) How many stereoisomers are there for each of the four fused-ring cyclic ethers shown below, molecules (1)–(4)?

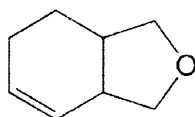
(+1) EACH CORRECT NUMBER



(1)

3

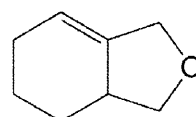
(cis ring fusion is meso, plus pair of enantiomers)



(2)

4

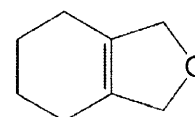
(two pairs of enantiomers)



(3)

2

(pair of enantiomers)

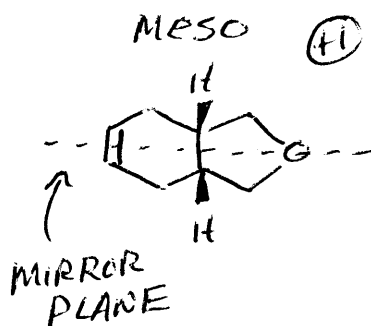


(4)

1

(achiral)

(B) Choosing from the possible stereoisomers in part (A), draw a *meso* compound. Similarly, draw a pair of diastereomers from among the stereoisomers in part (A).



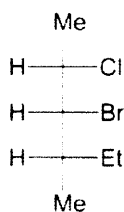
DIASTEREOMERS (+2)

- meso + 1 of the trans fused enantiomers of (1)

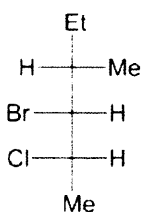
—OR—

- 1 from each pair of enantiomers of (2)

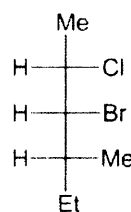
(C) Given the four Fischer projections below, describe the stereochemical relationship of structure (1) to each of the structures (2)–(4). In other words, what is the relationship of (1) to (2), of (1) to (3), and of (1) to (4)?



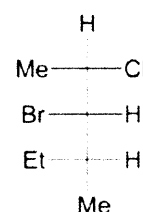
(1)



(2)



(3)



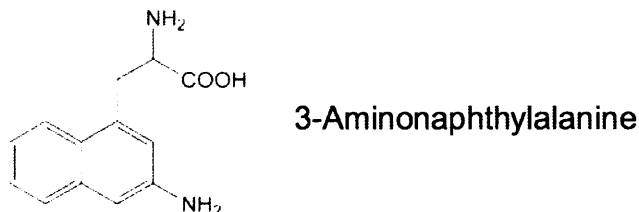
(4)

(1) & (2) SAME MOLECULE  
 (1) & (3) DIASTEREOMERS  
 (1) & (4) ENANTIOMERS

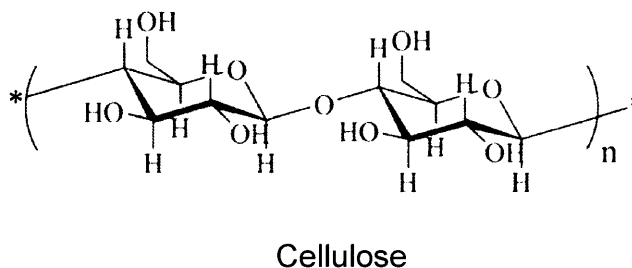
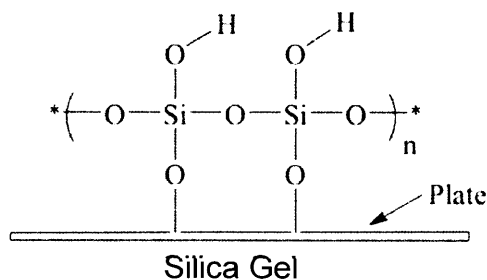
(+1) EACH PART

**Problem 5 (10 points; A & B = 5 points each)**

(A) A WashU graduate student has developed a new procedure for preparing racemic 3-aminonaphthylalanine, an unnatural amino acid. The melting point of the synthesized compound is 303-304 °C, in exact agreement with the literature value.



The student then carried out two different chromatographic procedures on the compound. Using thin layer chromatography (TLC) on silica gel, one spot was observed. In contrast, paper chromatography on cellulose gave two spots. Explain the different number of spots observed via TLC and paper chromatography.



**Procedure One:**

Solid support – Silica Gel  
 Eluent – 3:12:5 MeCO<sub>2</sub>H:*n*-BuOH:H<sub>2</sub>O  
 Visualization – Ninhydrin  
 Found – One spot, R<sub>f</sub> = 0.45

**Procedure Two:**

Solid support – Cellulose  
 Eluent – 3:12:5 MeCO<sub>2</sub>H:*n*-BuOH:H<sub>2</sub>O  
 Visualization – Ninhydrin  
 Found – Two spots, R<sub>f</sub> = 0.36, 0.55

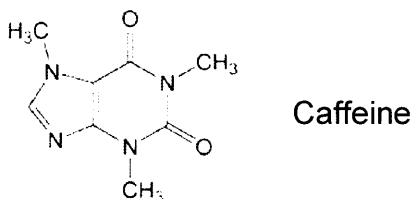
(+5) CELLULOSE IS CHIRAL, THEREFORE MAKES DIASTEREOMERIC INTERACTIONS WITH THE TWO ENANTIOMERS OF THE RACEMIC MIX, LEADING TO TWO DIFFERENT SPOTS. SILICA GEL IS ACHIRAL.

(B) When 1.0 gram (g) of caffeine is placed in a mixture of 25 mL of dichloromethane and 50 mL of water, the caffeine partitions, resulting in 0.20 g of caffeine in the water and 0.80 g of caffeine in the dichloromethane. What is the value of the distribution coefficient for caffeine between dichloromethane and water?

(+5)

$$\frac{0.8/25}{0.2/50} = 8:1$$

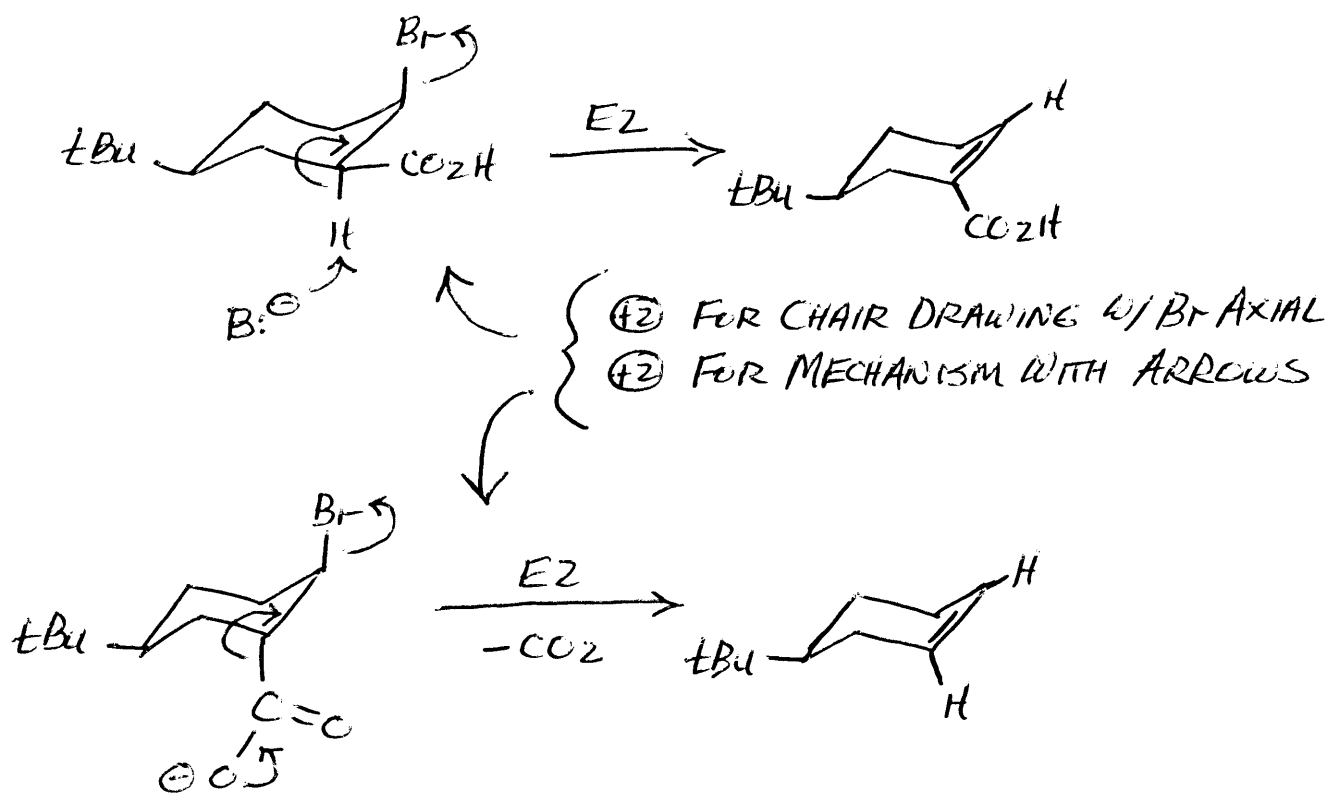
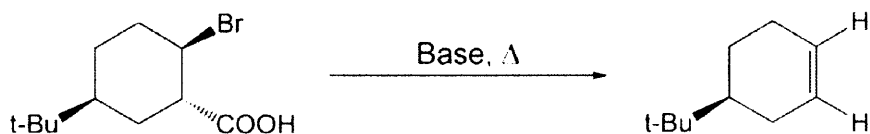
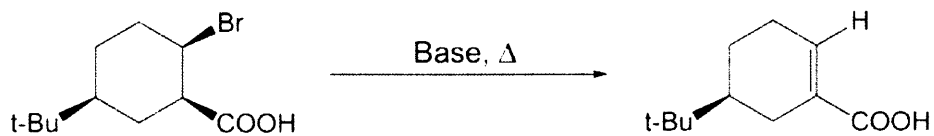
↑  
DISTRIBUTION COEFFICIENT



NOTE: NO PARTIAL CREDIT ON THIS PROBLEM. BOTH (A) & (B) GRADED ALL-OR-NONE

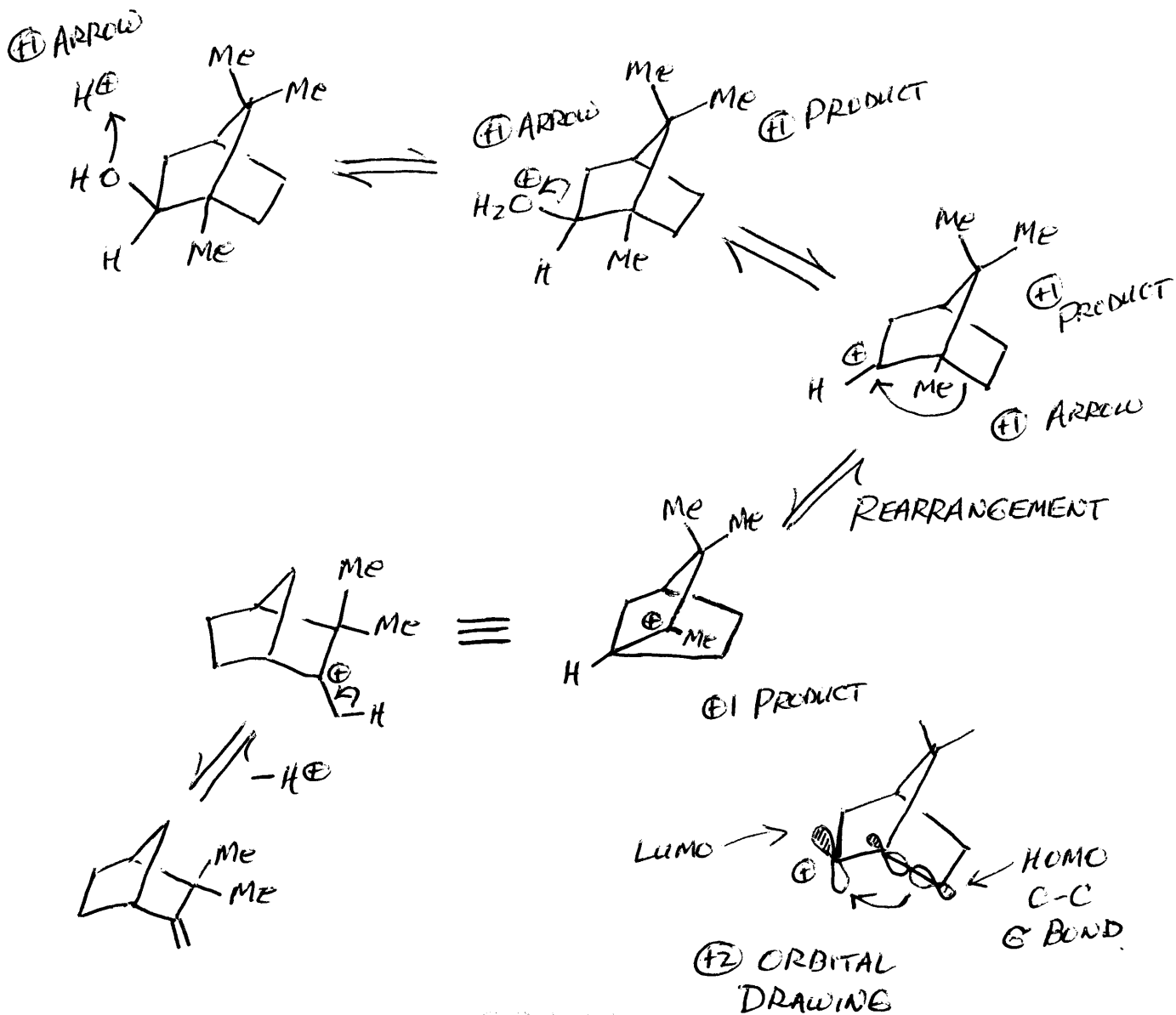
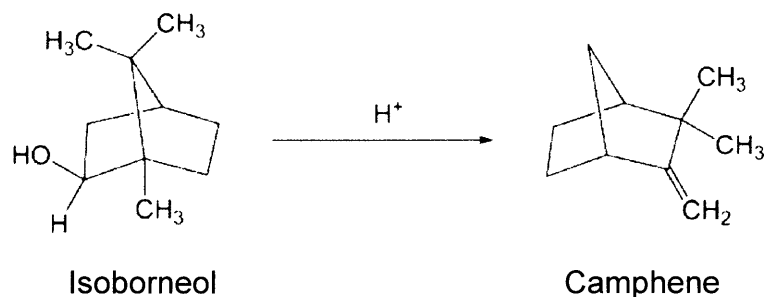
### Problem 6 (8 points)

Upon heating under basic conditions, the two reactions below produce the major products shown. Use 3D drawings to assist in writing the mechanisms leading to formation of each product, and to explain the different products.



**Problem 7 (8 points)**

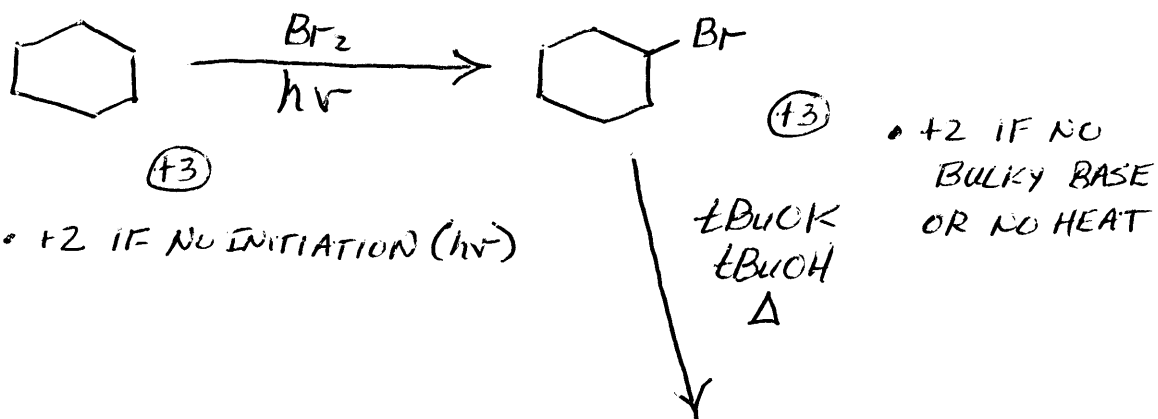
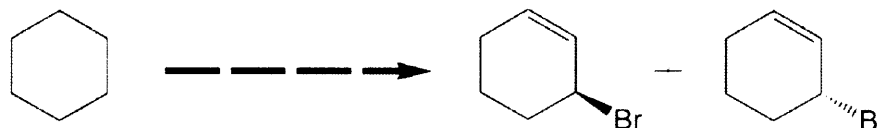
Isoborneol is a component of several essential oils, and is a natural insect repellent. It undergoes acid-catalyzed elimination to yield camphene. What type of reaction is occurring? Write the complete mechanism. Use an orbital drawing to explain the interconversion of the two key intermediates.





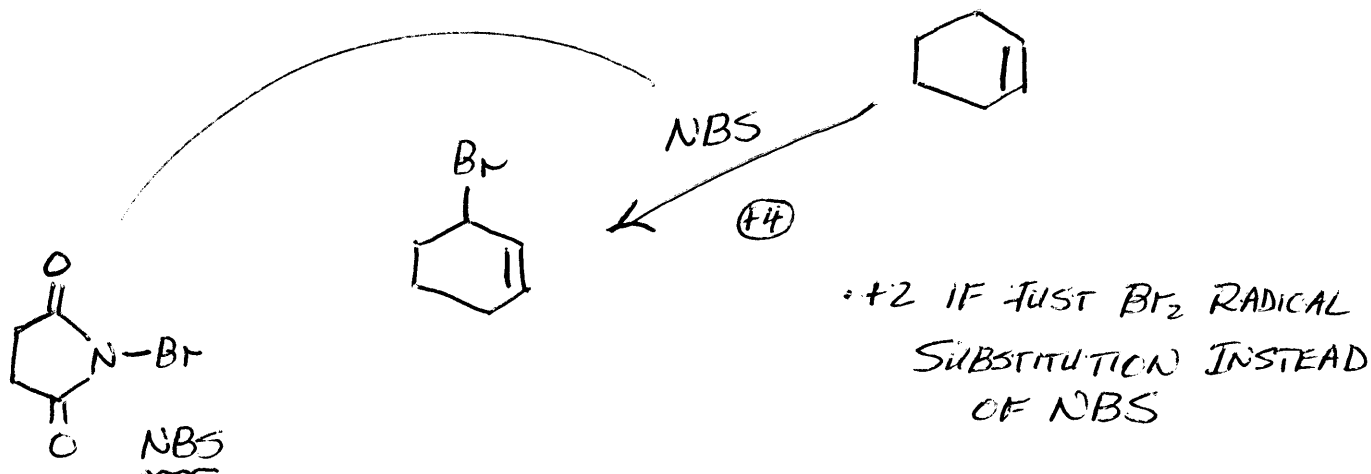
**Problem 8 (10 points)**

Provide a multi-step sequence of reactions to synthesize racemic 3-bromocyclohexene. You may start from cyclohexane and use any reactions and reagents. Mechanisms are not required – you only have to provide the starting materials, reaction conditions, and products for each step. Your synthesis will be evaluated based on the likely yield and selectivity of the proposed steps.



(+3) • +2 IF NO BULKY BASE OR NO HEAT

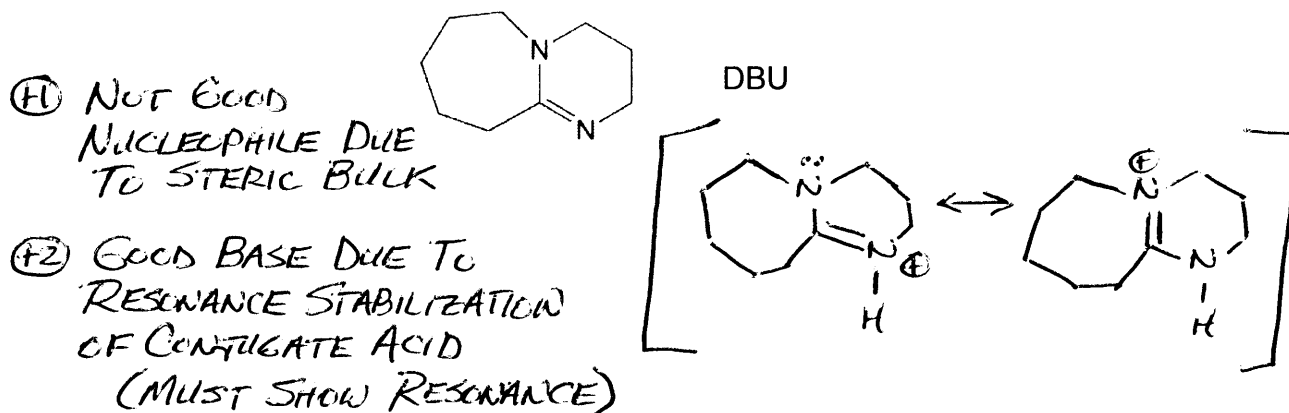
$\text{tBuOK}$   
 $\text{tBuOH}$   
 $\Delta$



SELECTIVE FOR ALLYLIC BROMINATION  
OVER ADDITION, SEE WADE SECTION 6-6

Problem 9 (10 points; A & B = 3 points each, C = 4 points)

- (A) The molecule commonly known as DBU (1,8-diazabicyclo[5.4.0]undec-7-ene) is a non-nucleophilic base sometimes used to facilitate E2 eliminations. Explain why DBU is a good base, and also explain why it is a poor nucleophile.

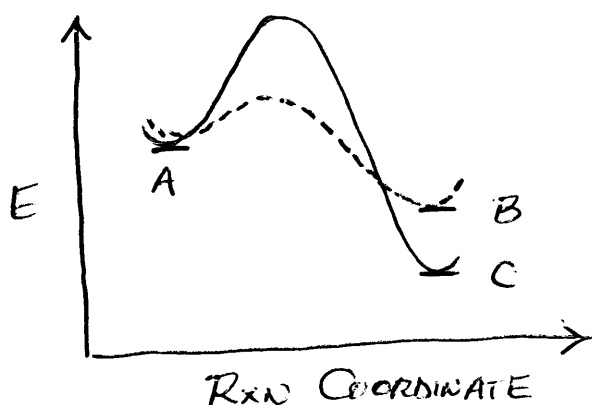


- (B) Concisely state the Hammond Postulate.

(+3) RELATED SPECIES THAT ARE CLOSE IN ENERGY ARE ALSO CLOSE IN STRUCTURE. THE TRANSITION STATE STRUCTURE RESEMBLES THE STRUCTURE OF THE CLOSEST STABLE SPECIES. OR SIMILAR...

[GRADED ALL-OR-NONE]

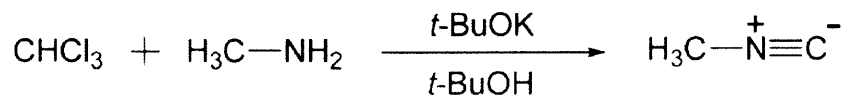
- (C) Draw a "reaction coordinate" diagram for the conversion of A into two alternative products, B and C, where B is the kinetic product and C is the thermodynamic product. Does the production of a kinetic product as the major product of a reaction violate the Hammond Postulate? Explain.



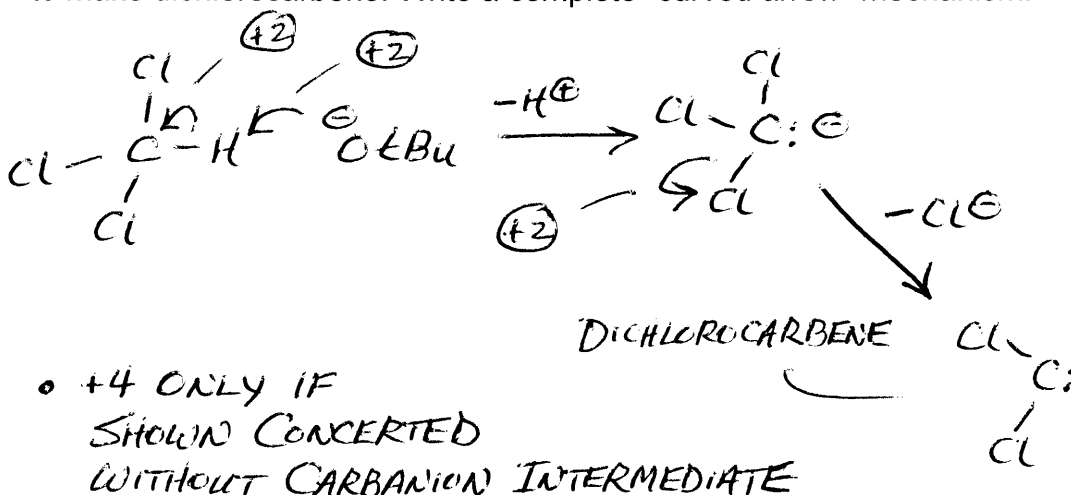
- (+1) RXN COORD DIAGRAM
- (+1) DIAGRAM WITH PROPER EXOTHERMIC RXNS & RELATIVE PRODUCTS
- (+1) NOT A VIOLATION OF THE HAMMOND POSTULATE
- (+1) EXPLAIN WHY NOT A VIOLATION, I.E.,  $A \rightarrow B$  &  $A \rightarrow C$  CAN BE COMPLETELY DIFFERENT RXN MECHANISMS

**Problem 10 (12 points; A & B = 6 points each)**

Chloroform ( $\text{CHCl}_3$ ) reacts with methylamine ( $\text{CH}_3\text{-NH}_2$ ) in the presence of potassium *t*-butoxide in *t*-butanol to form methyl isocyanide. The overall transformation is shown below. The product is a colorless liquid, which is used as a reagent in organic synthesis and as a ligand in organometallic chemistry.



- (A) The first part of the overall transformation is reaction of chloroform with *t*-butoxide to make dichlorocarbene. Write a complete "curved arrow" mechanism.



- (B) The second part of the overall transformation is dichlorocarbene reacting with methylamine to form the isocyanide. Write the full mechanism for this process. Some portions of the mechanism are analogous to the E2 elimination we studied.

