Name: _____ Student Number: _____

Chemistry 2600 Final Exam (Version A)
April 22nd, 2017

INSTRUCTIONS

1) Read the exam carefully before beginning. There are 8 questions on pages 2 to 16 followed by a periodic table and a blank page for rough work. You are also provided with a Spectroscopy Data Package (as posted on the class website). **Please ensure that you have a complete exam. If not, let an invigilator know immediately**. All pages must be submitted.
2) You are allowed to bring one index card (maximum size 3"x5") into the exam with you as a "cheat sheet". This card must be submitted with your exam.
3) You are allowed to bring a ruler and a molecular model kit.
4) You may use a calculator. It may not have wireless capability. You may not have any other electronic devices (phone, iPod, etc.) with you when you write the exam.
5) If your work is not legible, it will be given a mark of zero.
6) Marks will be deducted for incorrect information added to an otherwise correct answer.
7) When drawing molecules, clearly show any relevant stereochemistry. If a mixture of diastereomers is produced, draw both/all of them.
8) **DO NOT OPEN THE EXAM UNTIL YOU ARE TOLD TO BEGIN.**
   Beginning prematurely will result in removal of your exam paper and a mark of 0.
9) You have **3 hours** to complete this exam. Nobody may leave the exam room during the first hour or the last 15 minutes of the exam.

Q	Mark
1	/ 17
2	/ 10
3	/ 5
4	/ 6
5	/ 16

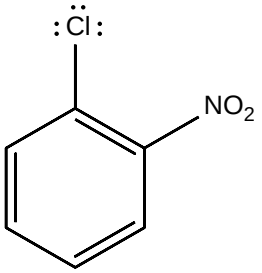
Q	Mark
6	/ 15
7	/ 5
8	/ 1

Total	/ 75

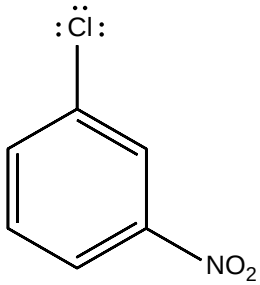
Name: _____ Student Number: _____

1. You wish to prepare various isomers of chloronitrobenzene from benzene. **[17 marks]**

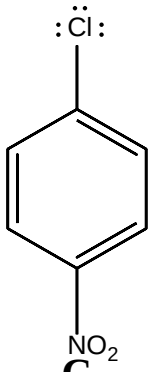
For simplicity, they have been labeled **A**, **B** and **C**:



A



B



C

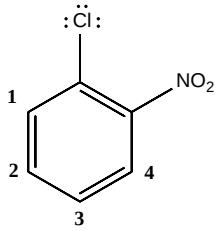
(a) Consider how ^{1}H NMR can be used to identify which product(s) are made from each reaction.

For each isomer, complete the table provided to clearly indicate:

- The relative integration of each peak
- The multiplicity of each peak <u>if</u> no long range coupling is observed
- If each peak could reasonably be expected to experience long range coupling.
- If long range coupling is expected, write the number for the proton(s) coupled to. If long range coupling is <u>not</u> expected, write "N/A" or leave the last box blank.

Isomer A has been numbered for you. Please number **Isomers B** and **C** on the pictures next to each table. Use one number for each peak expected on the ^{1}H NMR.

Isomer A *[3 marks]*



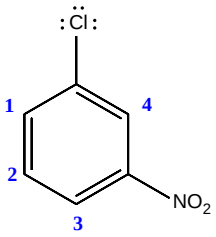
A

Peak	Integration	Multiplicity	Might have long range coupling? (yes/no)	Long range coupling is with which proton(s)?
1	1 H	doublet	yes	3
2	1 H	triplet	yes	4
3	1 H	triplet	yes	1
4	1 H	doublet	yes	2

Name: _____ Student Number: _____

1. *continued…*

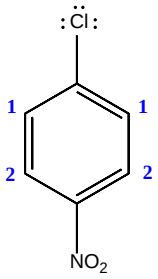
Isomer B *[3 marks]*



B

Peak	Integration	Multiplicity	Might have long range coupling? (yes/no)	Long range coupling is with which proton(s)?
1	1 H	doublet	yes	3 and 4
2	1 H	triplet	no	
3	1 H	doublet	yes	1 and 4
4	1 H	singlet	yes	1 and 3

Isomer C *[3 marks]*



C

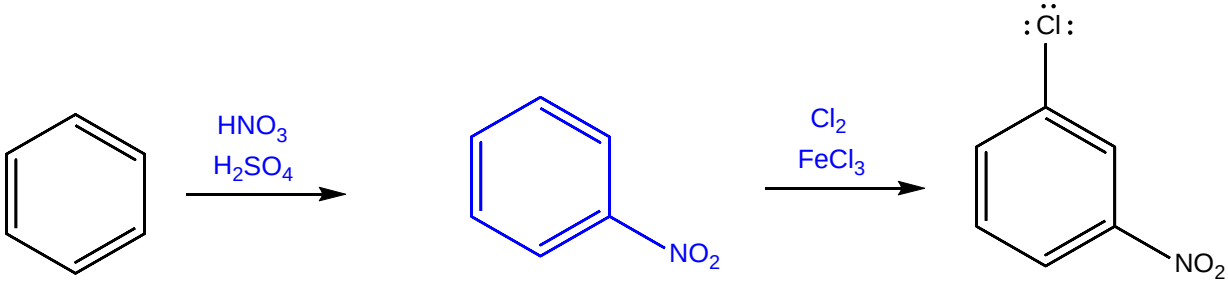
Peak	Integration	Multiplicity	Might have long range coupling? (yes/no)	Long range coupling is with which proton(s)?
1	1 H*	doublet	no	
2	1 H*	doublet	no	

** There is a 1 : 1 ratio between the integrations for these peaks. While each peak represents 2 H, that won't be obvious from the ^{1}H NMR. That said, tests that listed both peaks as integrating to 2 H were given credit.*

Name: _____ Student Number: _____

1. *continued…*

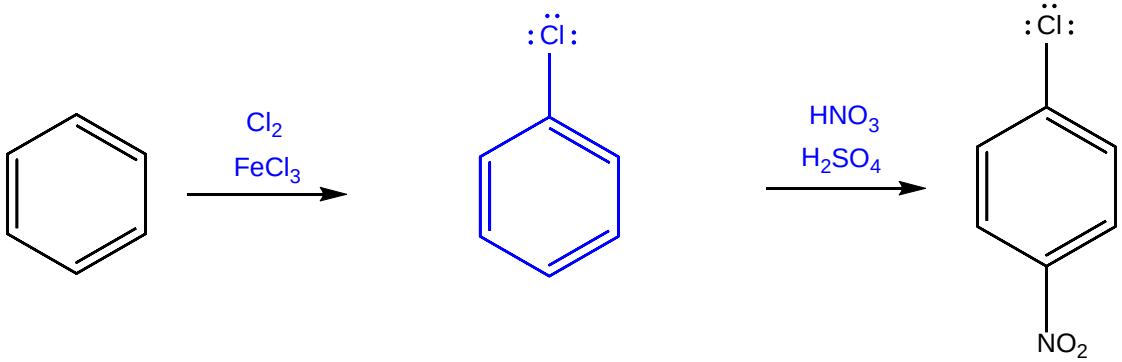
(b) If you wish to prepare **Isomer B** (as the major product), what sequence of reactions should you use? *[3 marks]*



B

The nitro group is a meta director, so add it first.

(c) If you wish to prepare **Isomer C** (as the major product), what sequence of reactions should you use? *[3 marks]*

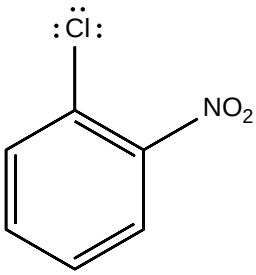


C

The chlorine atom is an ortho/para director, so add it first.

(d) Preparing **Isomer A** as the major product is a more difficult task. Even in the industrial process used to make it commercially, it's only a minor product (~35% Isomer A; ~65% something else). Why? *[2 marks]*

The chlorine atom is an ortho/para director but, for steric reasons, the para product is favoured. Thus, making 1-chloro-2-nitrobenzene as the only product would be challenging.



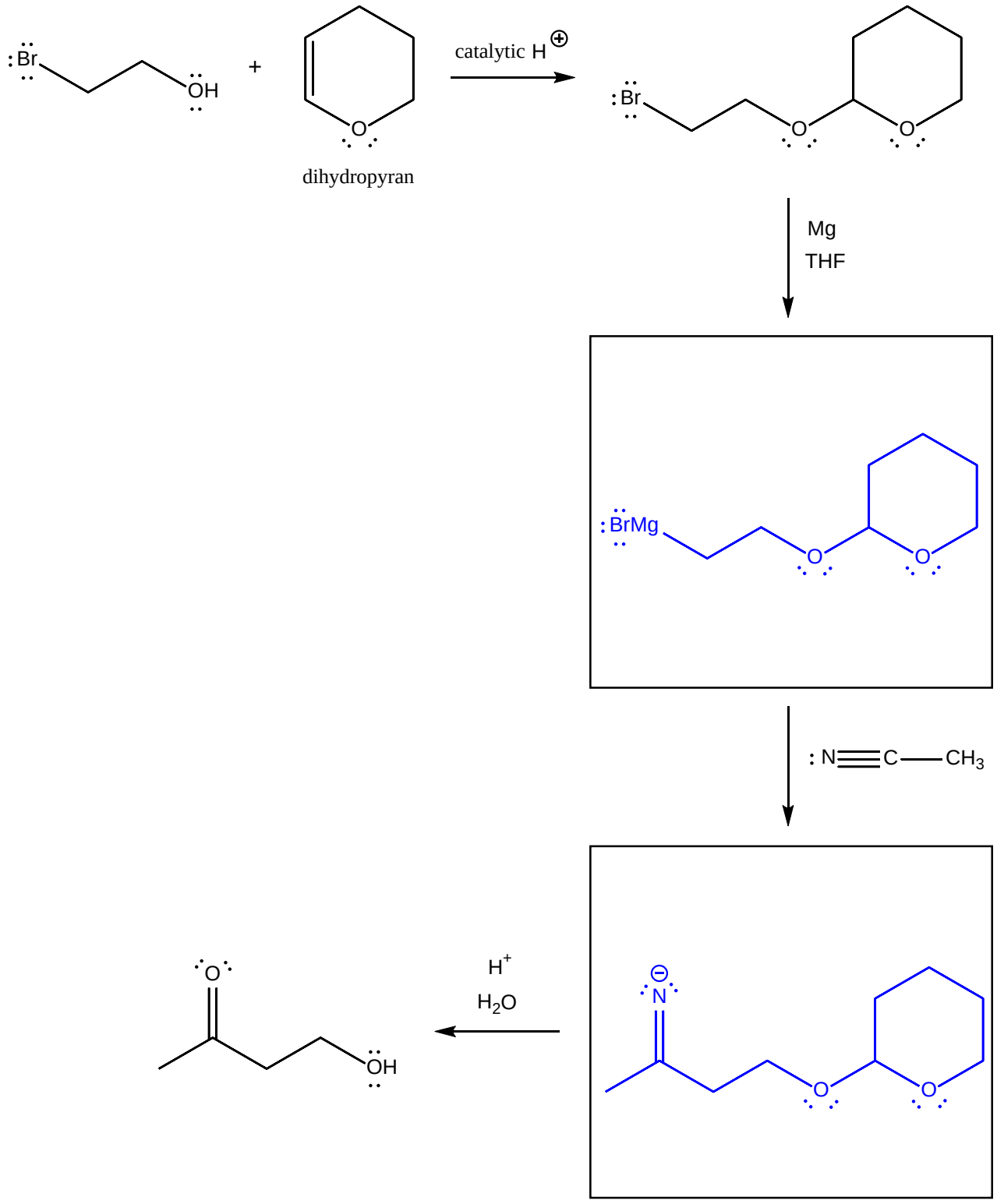
A

The only way to favour the ortho product would be to put a blocking group in the para position (opposite the Cl), but the usual choice of blocking group is a nitro group. It wouldn't be possible to remove that nitro group without also removing the desired nitro group.

Converting the blocking nitro group into an amino group before adding the desired nitro group might work since the amino group would be protonated by the strong acids used to add the nitro group – turning it into a meta-directing $-NH_3^+$ group. This would be a lot of work, but would probably be the most effective way to make Isomer A without too many by-products.

Name: _____ Student Number: _____

2. Dihydropyran can be used as a protecting group for alcohols: **[10 marks]**



Name: _____ Student Number: _____

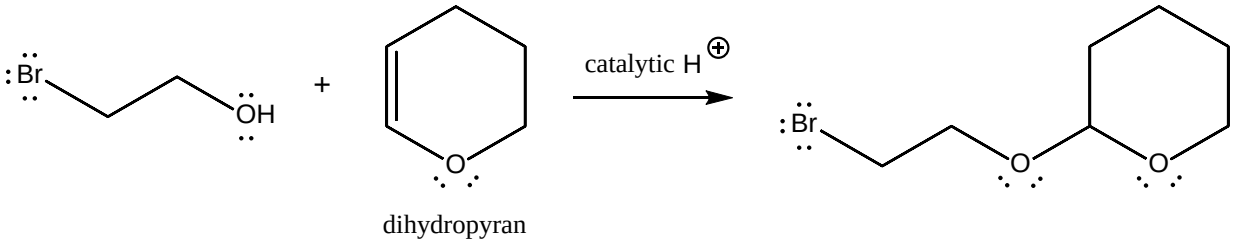
2. *continued…*

(a) **<u>On the previous page</u>**, draw the missing intermediate products in the boxes provided. *see previous page* *[2 marks]*

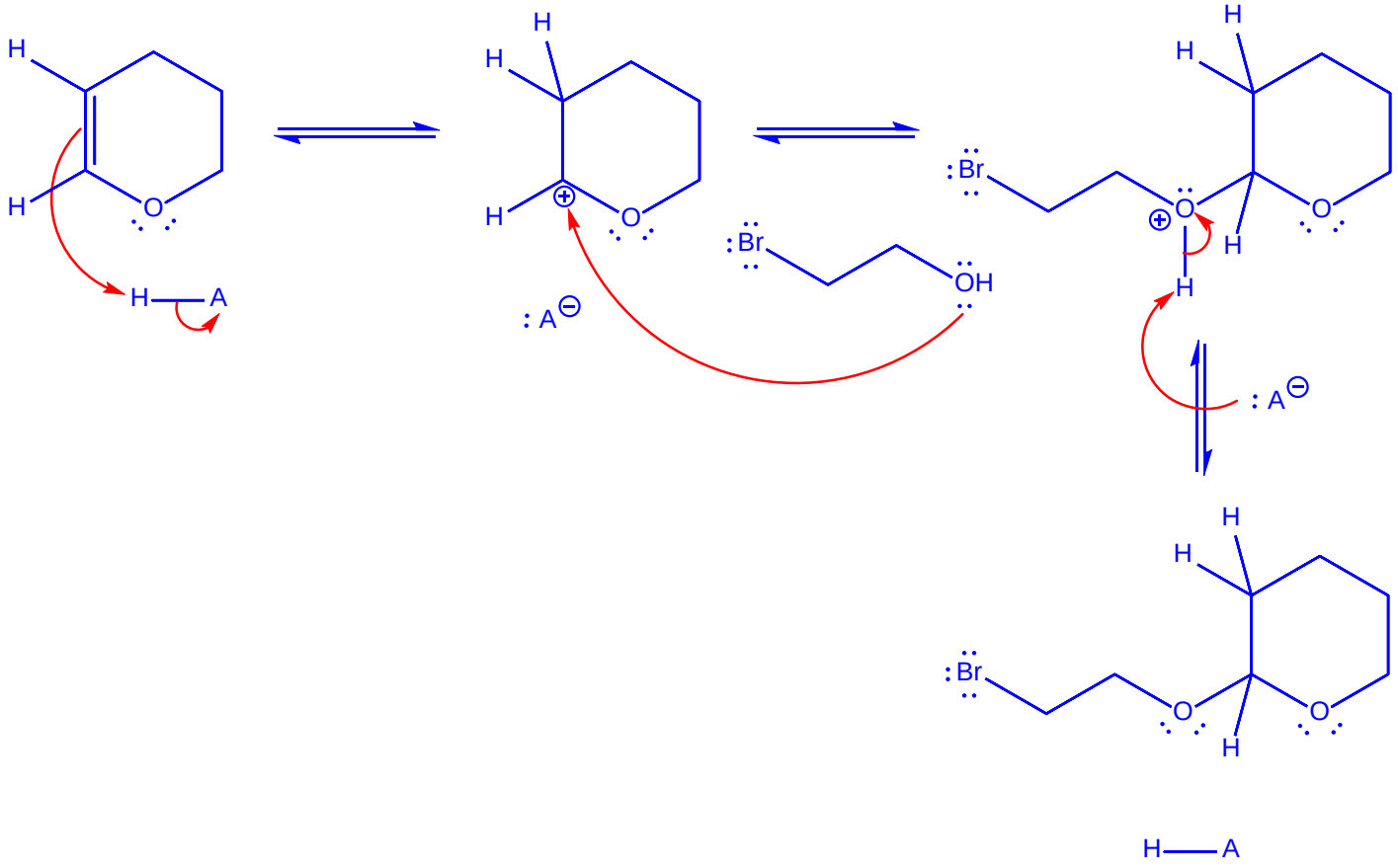
(b) Why is a protecting group necessary for this reaction sequence to work? *[2 marks]*

Grignard reagents cannot be formed in the presence of acidic protons (such as the OH in an alcohol). In order to form the Grignard reagent, the alcohol must first be protected so that it doesn't have any acidic protons.

(c) Propose a reasonable mechanism for the reaction between 1-bromoethanol and dihydropyran. You may use *HA* as shorthand for the catalytic acid and A^- as shorthand for its conjugate base. *[3 marks]*



dihydropyran

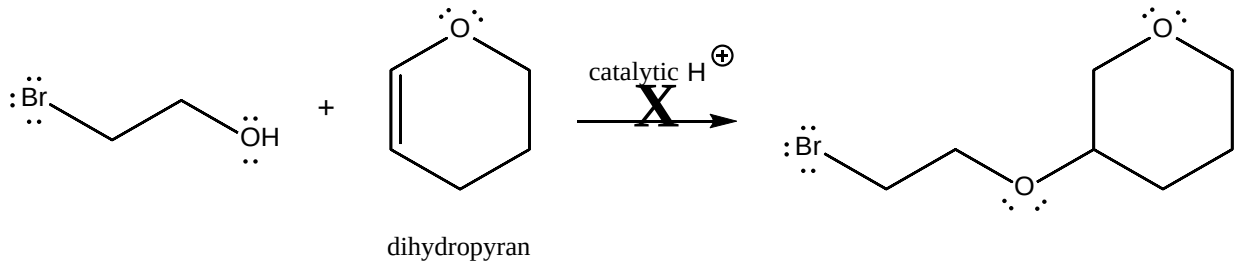


Name: _____ Student Number: _____

2. *continued…*

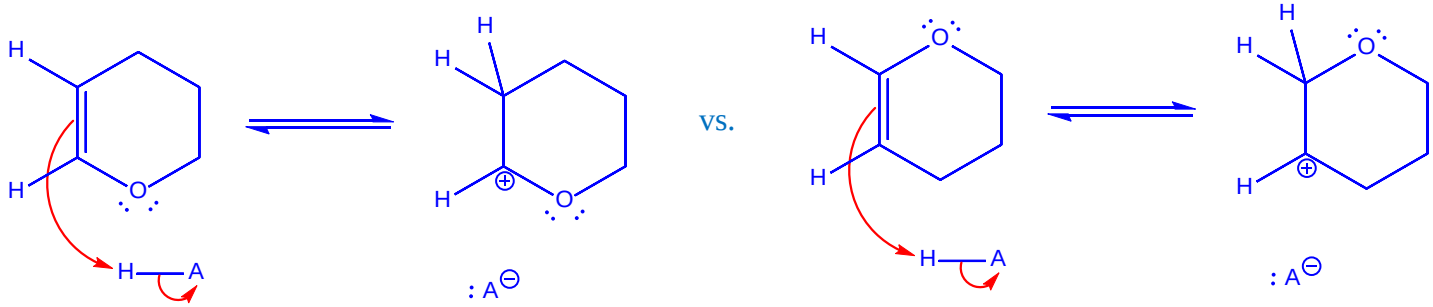
(d) With reference to your mechanism in part (c), explain the regiochemistry observed in the reaction between an alcohol and dihydropyran.

In other words, why does the reaction below **NOT** occur? *[3 marks]*

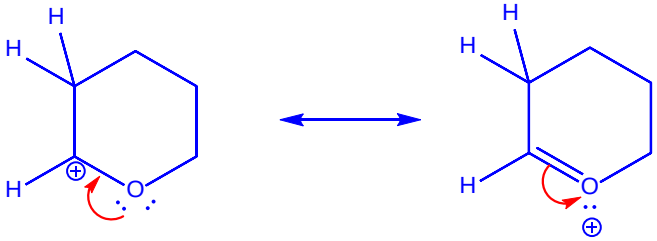


dihydropyran

When the dihydropyran is protonated, we could imagine adding H to either carbon of the C=C double bond. These are the two carbocations that would result:



The carbocation on the left is *much* more stable than the one on the right. This is because the positive charge of the carbocation on the left can be delocalized onto the oxygen atom. This is an example of resonance stabilization:



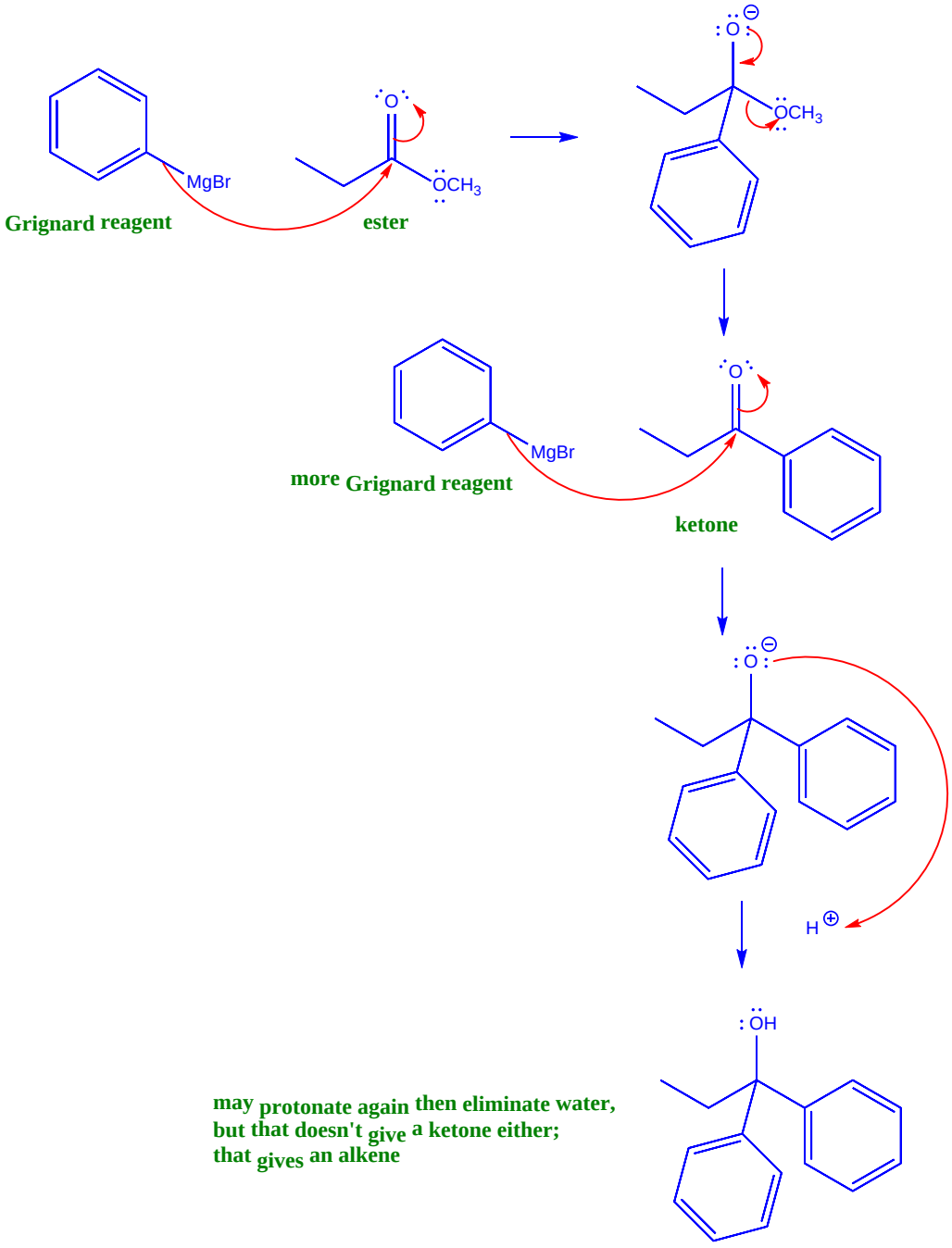
There is no way to delocalize the positive charge of the carbocation on the right.

As such, the carbocation on the left is formed preferentially and the reaction proceeds as shown in part (c) of this question (and not as shown in part (d)).

Name: _____ Student Number: _____

3. Explain why you cannot prepare a ketone by reacting an ester with a Grignard reagent. Your answer should include a mechanism. You may choose any ester and any Grignard reagent to illustrate your point. **[5 marks]**

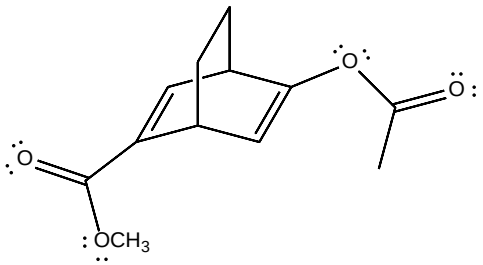
Grignard reagents react with ketones even more readily than they react with esters. As such, a Grignard reagent will always add TWICE to an ester, giving a tertiary alcohol* as shown below:



** If the ester were an ester of formic acid, you would get a secondary alcohol instead – but you wouldn't have been trying to make a ketone. The reactive intermediate would have been an aldehyde instead of a ketone.*

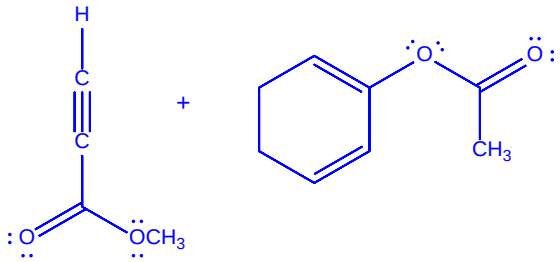
Name: _____ Student Number: _____

4. Consider the molecule below: **[6 marks]**



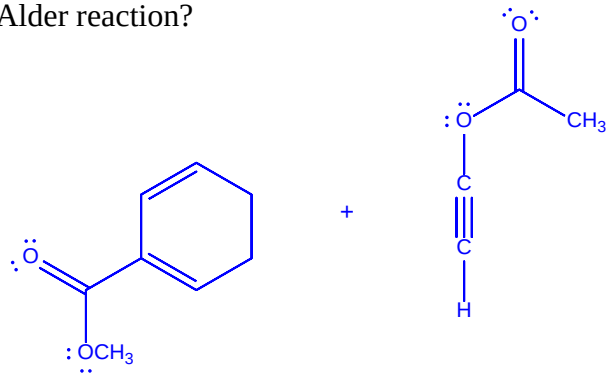
Esters can be either electron-donating or electron-withdrawing depending on whether the carbonyl carbon is attached to the diene/dienophile (ester as EWG) or whether the oxygen atom is attached to the diene/dienophile (ester as EDG).

(a) What compounds would you react to prepare this compound using a normal Diels-Alder reaction? *[2 marks]*



Normal Diels-Alder reactions have electron-donating group(s) attached to the diene and electron-withdrawing group(s) attached to the dienophile.

(b) What compounds would you react to prepare this compound using an "inverse electron demand" Diels-Alder reaction? *[2 marks]*



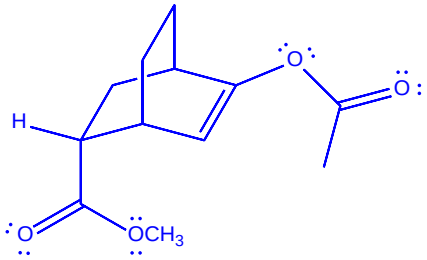
Inverse electron demand Diels-Alder reactions have electron-withdrawing group(s) attached to the diene and electron-donating group(s) attached to the dienophile.

(c) Is the compound above the *exo* product, the *endo* product, both or neither? Explain. Your answer should make it clear that you know what the terms *exo* and *endo* mean. *[2 marks]*

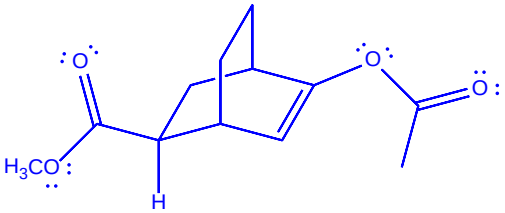
Neither.

Because the dienophile is an alkyne, it is linear. As such, there is no "tucking under" or "sticking out" of the substituent(s).

If the dienophile had been an alkene instead of an alkyne, the products of the normal Diels-Alder reaction would have looked like this:



endo



exo

Name: _____ Student Number: _____

5. The following page contains spectra for Unknown X. **[16 marks]**

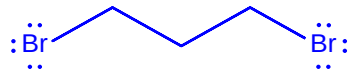
(a) Identify Unknown X based on these spectra. Draw your answer in the box provided below.

(b) Use this page to explain your logic (including how you determined the molecular formula).

(c) On both NMR spectra, assign as many peaks as you can by numbering the peaks from left to right, redrawing Unknown X in the box provided, and labeling each carbon or hydrogen atom with the appropriate peak number. *For atoms that cannot be assigned with certainty, list the signals to which they might reasonably correspond.*

(d) Label any important peaks on the Mass Spectrum (with formulas of the fragments).

Unknown X:



One Way to Arrive at the Answer

Step 1: Work out the Molecular Formula

- Molecular ion is m/z 200
- $[M]^+ : [M+2]^+ : [M+4]^+$ peak ratio is about 1 : 2 : 1 therefore there are probably two Br. This is backed up by the peaks at 121 and 123 with a 1 : 1 ratio (200 – 79 = 121, and 1 : 1 ratio suggests presence of one Br)
- $[M]^+ : [M+2]^+$ appears to be 3 : 1 therefore there is probably one Cl (this is backed up by the presence of a tall peak at m/z 41 (76 – 35 = 41; 78 – 37 = 41)
- ^{13}C NMR shows two signals, so there are at least two C
- ^{1}H NMR has two signals, one which integrates to twice as much as the other, so there are at least three H (and the number of H is a multiple of three)
- $C_2H_3Br_2$ adds up to 185, leaving 15 g/mol unaccounted for. This can't be a halogen or O or NH, so it's most likely CH_3. If so, that gives a molecular formula of $C_3H_6Br_2$ and indicates that the molecule has some symmetry.

Step 2: Calculate Unsaturation Index (Degrees of Unsaturation)

- $DU = \frac{2C+2+N-X-H}{2} = \frac{2(3)+2-2-6}{2} = \frac{0}{2} = 0$
- Therefore, there are no rings or multiple bonds in this molecule

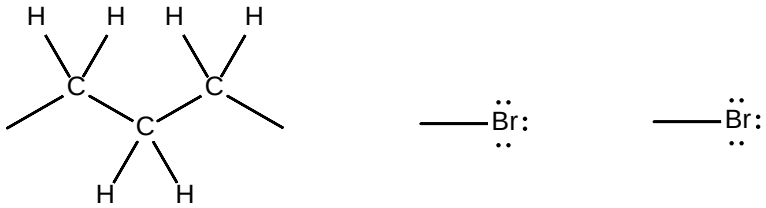
Step 3: Gather Useful Information from the Spectra

- There is nothing useful on the IR. This is not surprising given the molecular formula.
- The ^{1}H NMR has two peaks:
  - A triplet integrating to 4 H suggests two CH_2 groups, each next to a different CH_2
  - A pentet integrating to 2 H suggests one CH_2 group next to either two CH_2 groups or a CH and a CH_3 (given that there's only one other peak, it must be next to two CH_2 groups)
- The ^{13}C NMR has two peaks, so there must be two equivalent C (consistent with ^{1}H NMR)

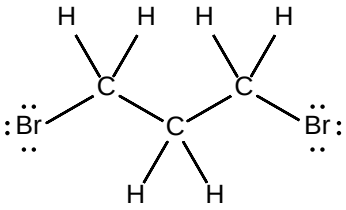
Name: _____ Student Number: _____

Step 4: Put Together the Pieces

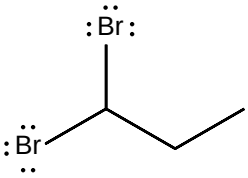
- We therefore have three pieces:



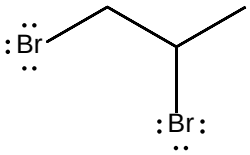
- There is only one way to put them together:



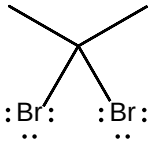
Once you have the molecular formula, an alternative approach would be to draw all four isomers of $C_3H_6Br_2$ and identify the only one that has two chemical environments for C and two chemical environments for H:



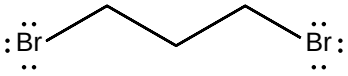
3 C environments
3 H environments



3 C environments
4 H environments
(the two H at the left are diastereotopic)



2 C environments
1 H environment

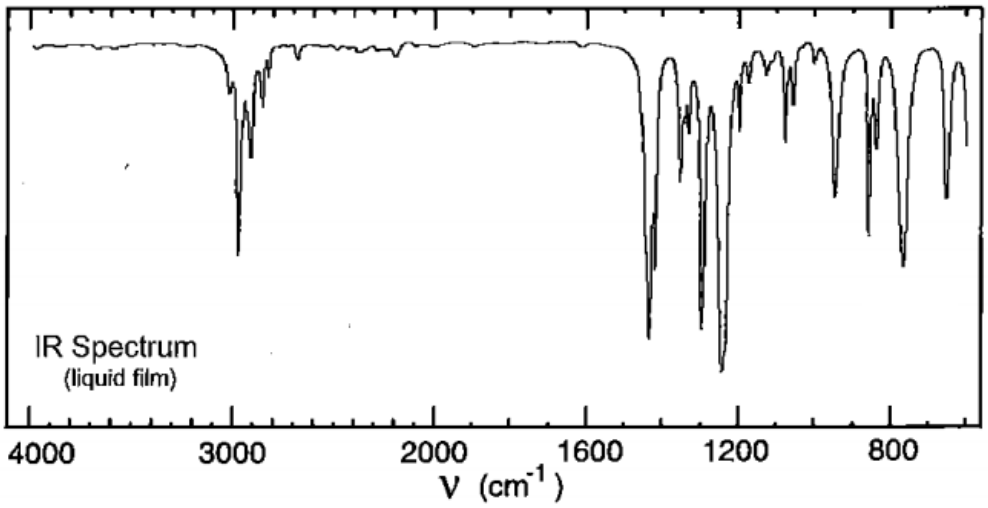


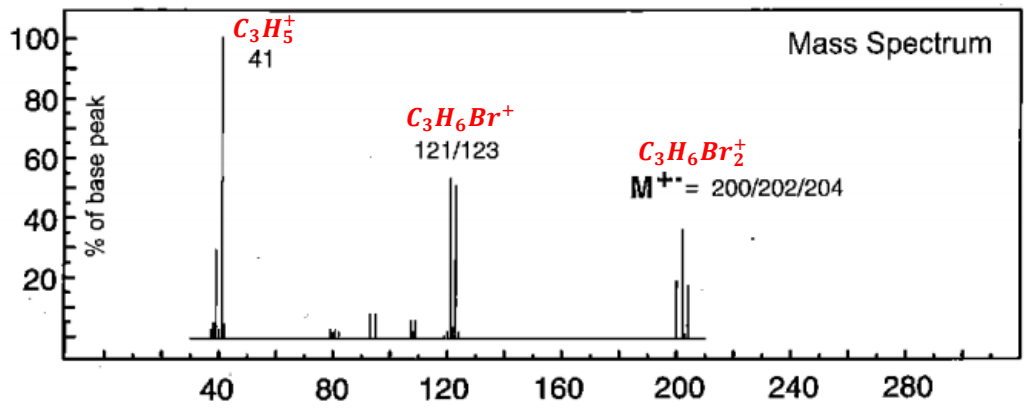
2 C environments
2 H environments

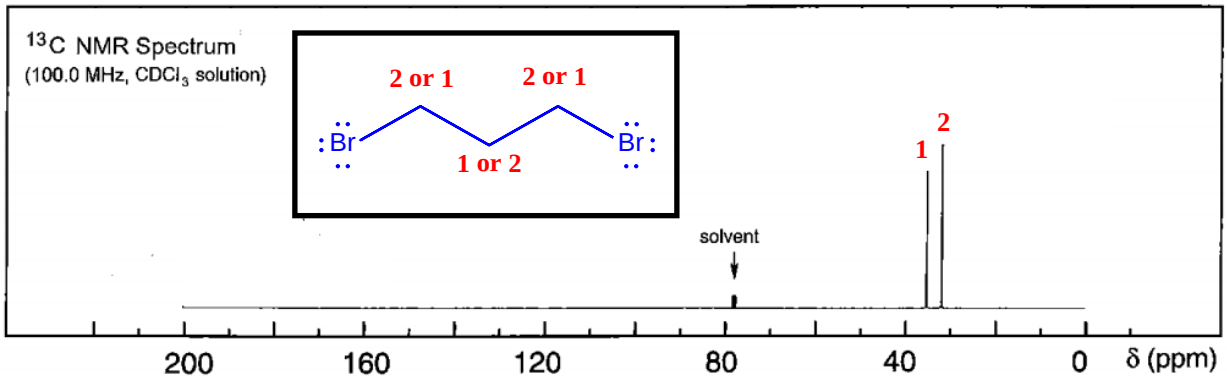
Then confirm that this structure is consistent with the other spectral data (e.g. integrations and multiplicities of the peaks on the ^1H NMR).

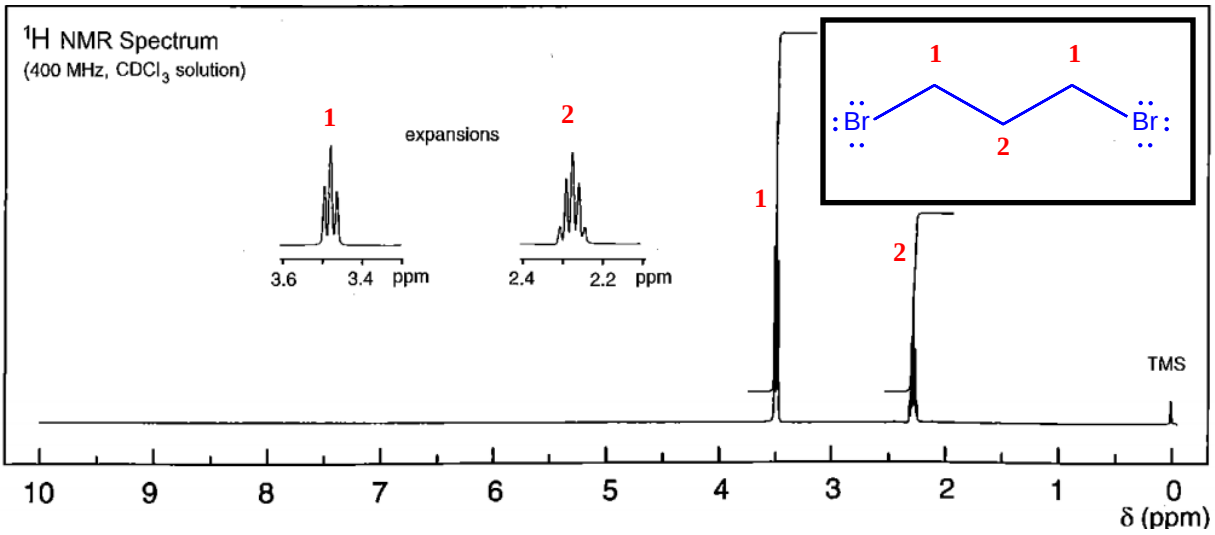
Name: _____ Student Number: _____

5. *continued…*





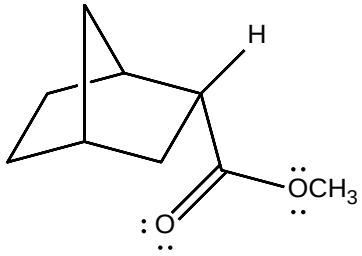




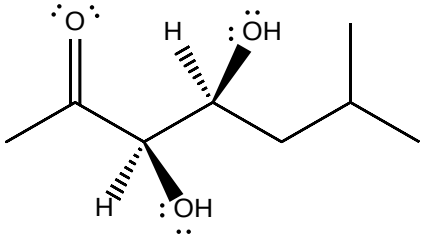
Name: _____ Student Number: _____

6. Choose any **three** of the molecules below and propose a synthesis for each one. **[15 marks]**

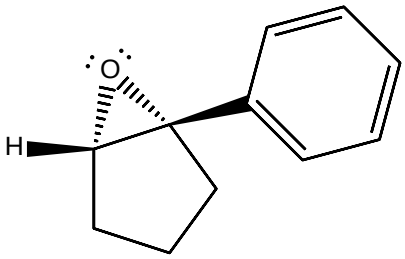
- If your synthesis involves more than one step, write an equation for each step. Show all required reactants. Number steps within a reaction if order of addition is important.
- All organic reactants must be stable compounds containing **no more than five carbon atoms**. They may be **hydrocarbons, alkyl halides or alcohols** and may contain C=C or C≡C bonds. The only exception to this rule is that you are **also allowed** to use **benzene, bromobenzene or phenol**.
- If you wish to use an organic reactant (including Grignard reagent) that does not meet these requirements, you must show how to make it from starting materials that do.
- You may use any inorganic reagents, acids, bases, catalysts, etc.
- Acids, bases, catalysts, etc. do not need to meet the "organic reactant" requirements if the organic part will not be present in the final product.
- Clearly indicate stereochemistry of reaction products where appropriate. Assume that all stereochemistry shown is relative and that you are to make racemic product.
- You are **not** required to show mechanisms for this question.
- There are three pages after this page. Use one of those pages for each synthesis and clearly identify the synthetic target at the top of the page. This page is scrap paper.
- If you give more than three syntheses, I will only mark the first three (ignoring any that are crossed out).



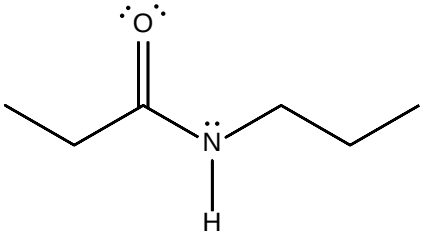
Looks like a Diels-Alder product but needs a double bond…



Could probably add the two OH by dihydroxylation of an alkene…
Make the alkene via an aldol?



Easiest way to make an epoxide is from an alkene…
Make the alkene by having PhLi or PhMgX react w/ cyclopentanone?



Make amide from amine + acid chloride…
Acid chloride comes from carboxylic acid which comes from alcohol…
Amine could be made from azide?

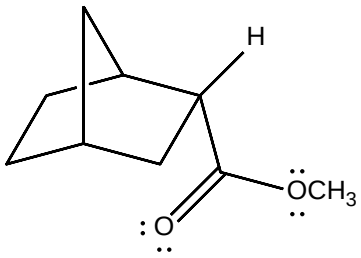
The answers in this answer key are representative.
There will be other ways each molecule can be made.

You were not asked to provide a retrosynthetic analysis; however, I have included one here to more clearly show the logic behind the synthetic proposal.

Name: _____ Student Number: _____

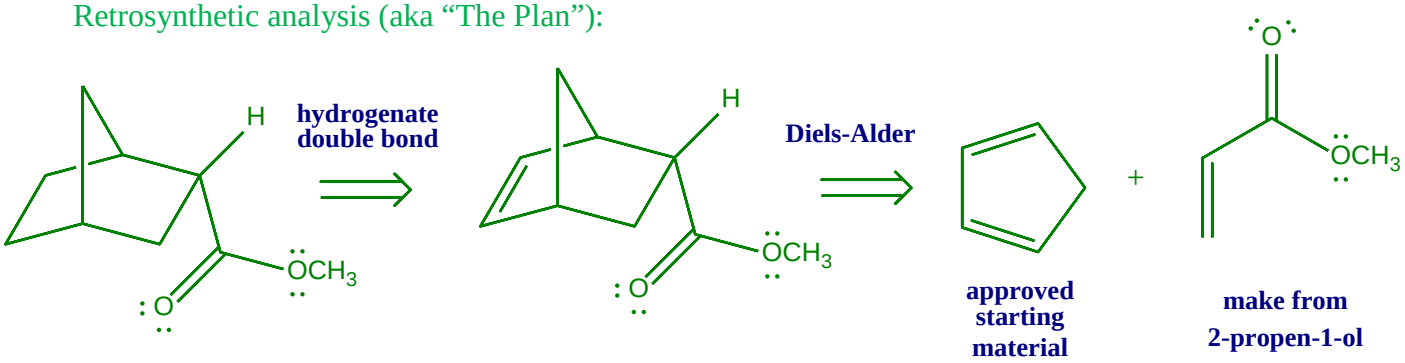
6. *continued…* *[5 marks]*

Synthetic Target #1:

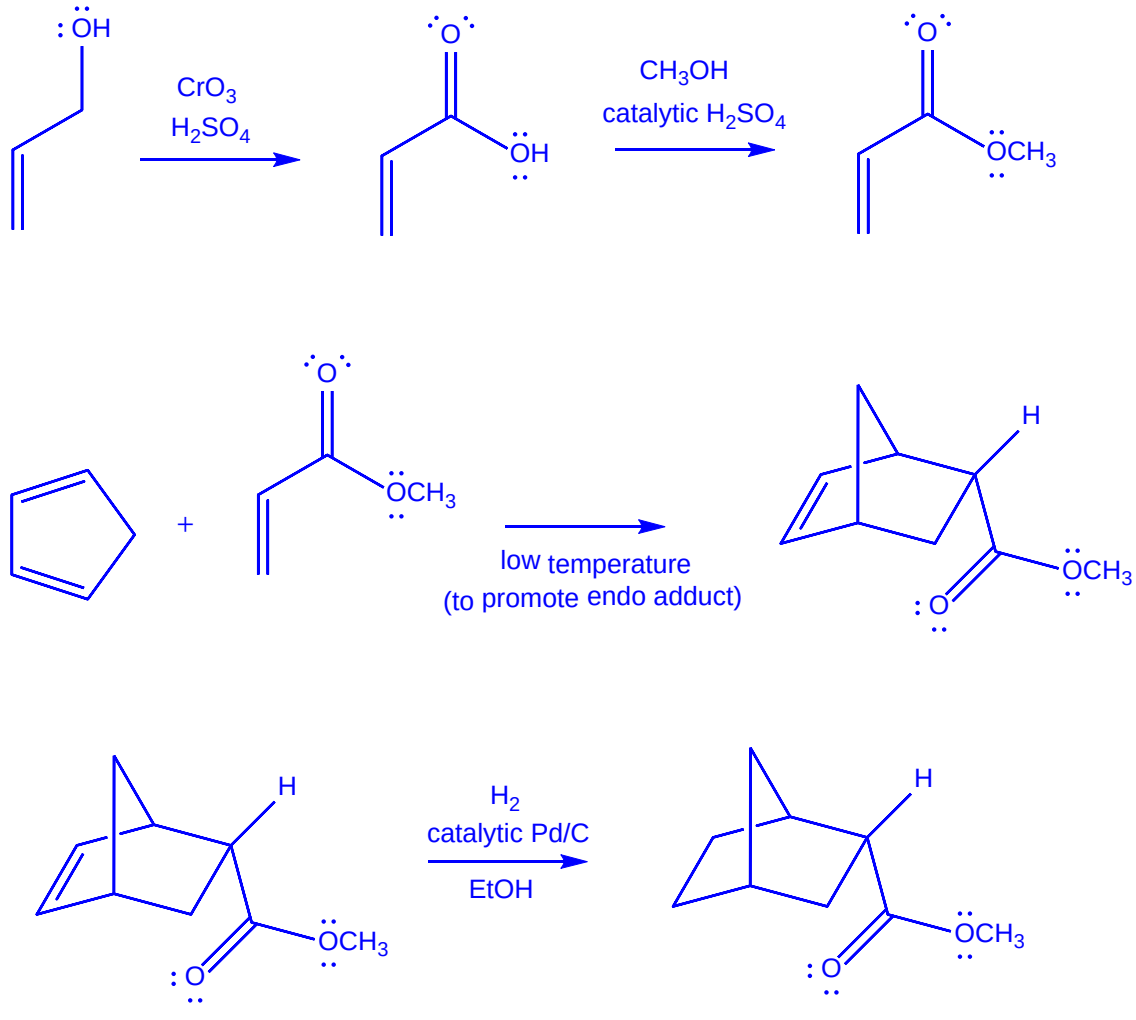


Synthesis:

Retrosynthetic analysis (aka "The Plan"):



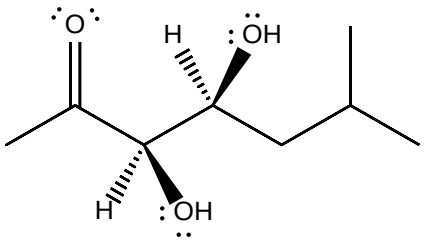
Synthetic Proposal:



Name: _____ Student Number: _____

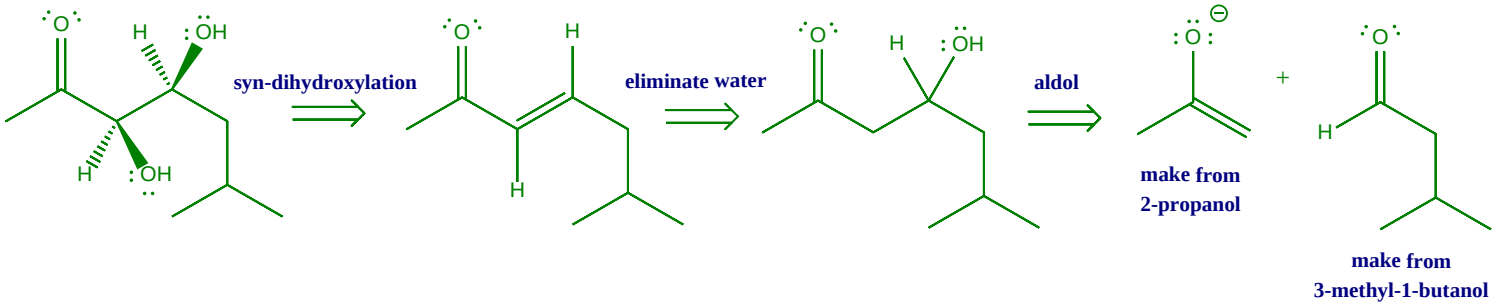
6. *continued…* *[5 marks]*

Synthetic Target #2:

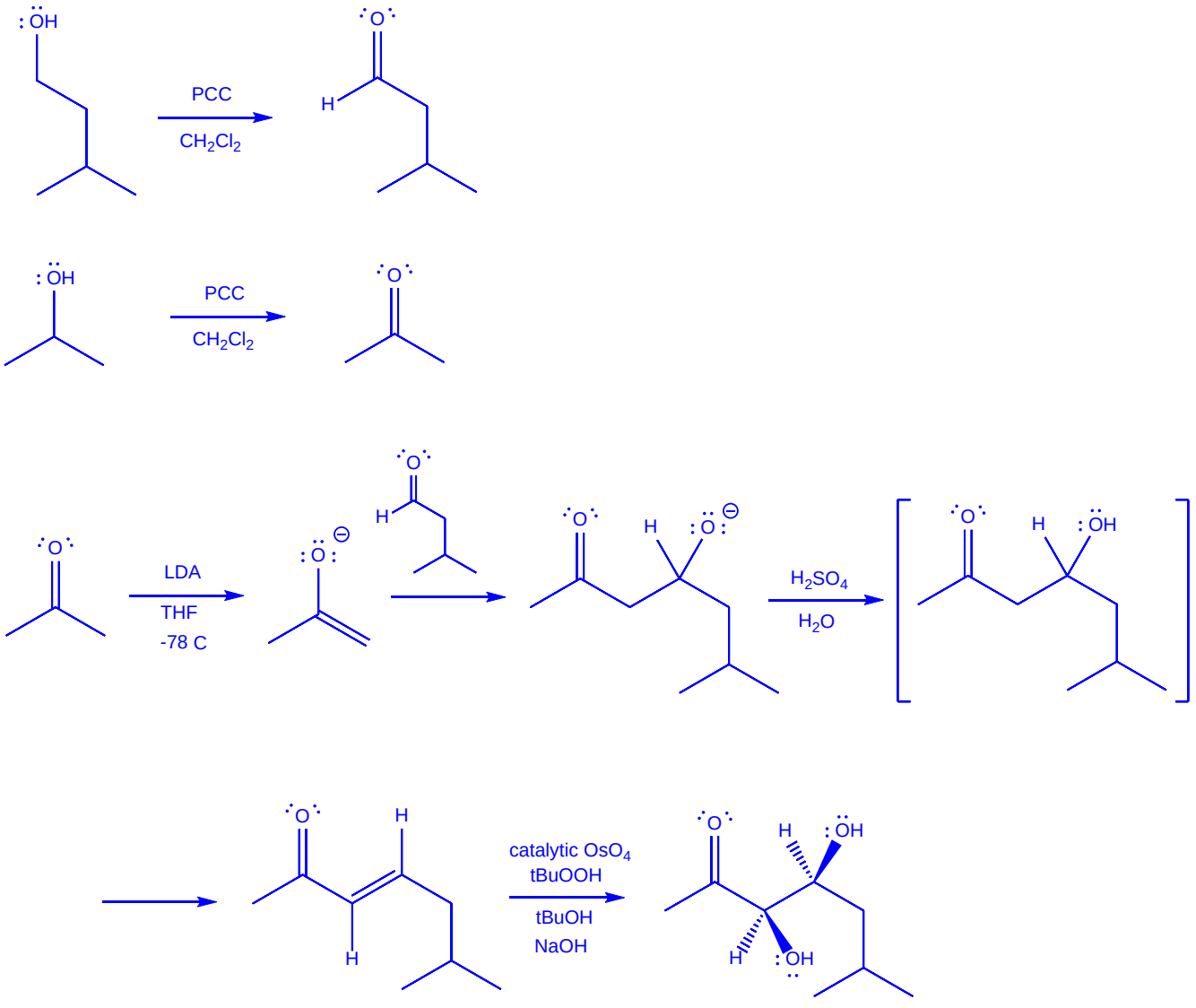


Synthesis:

Retrosynthetic analysis (aka "The Plan"):



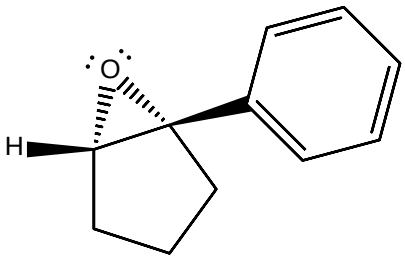
Synthetic Proposal:



Name: _____ Student Number: _____

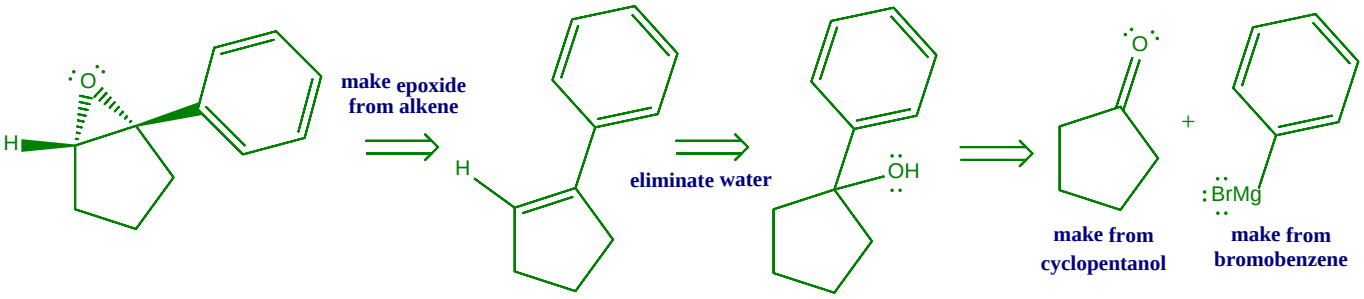
6. *continued…* *[5 marks]*

Synthetic Target #3:

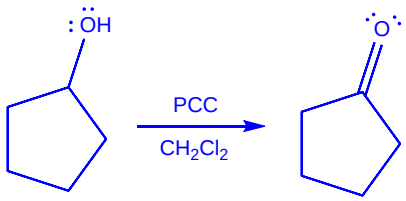


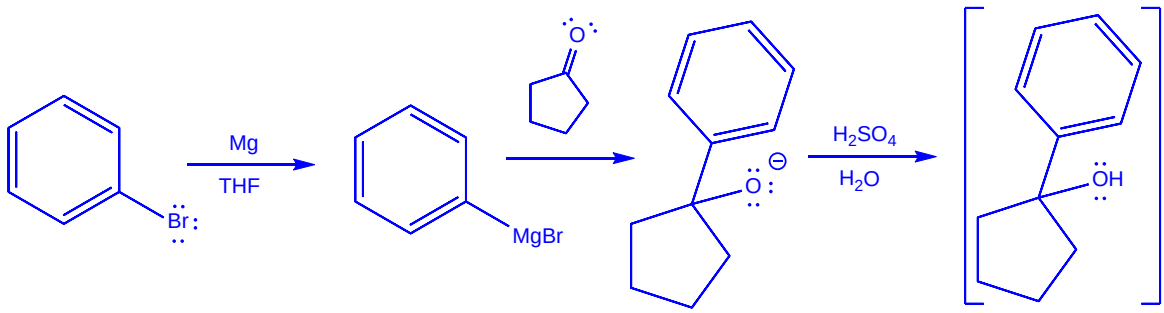
Synthesis:

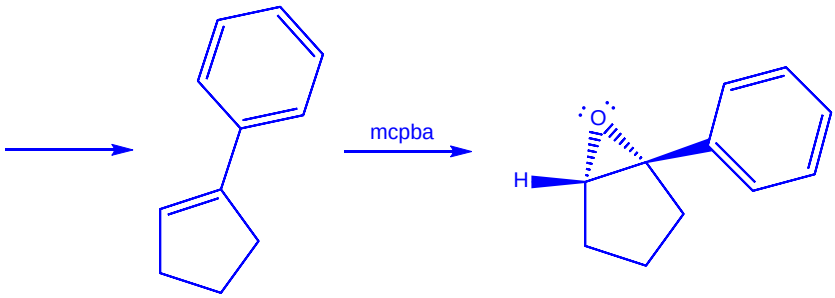
Retrosynthetic analysis (aka "The Plan"):



Synthetic Proposal:



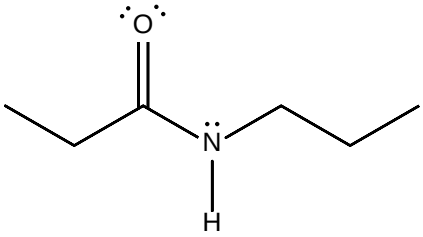




Name: _____ Student Number: _____

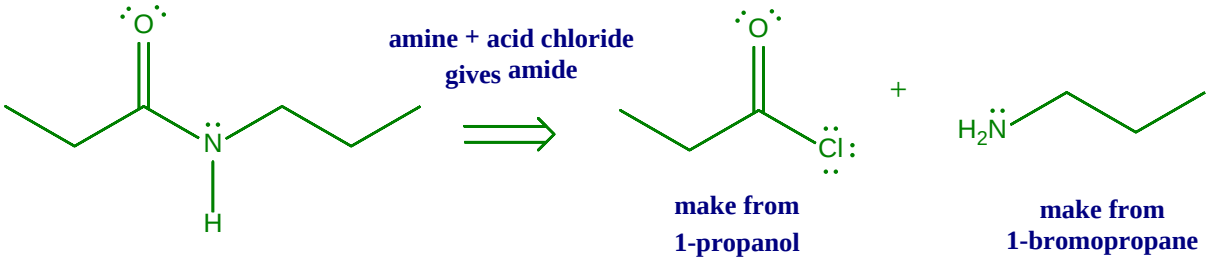
6. *continued…* *[5 marks]*

Synthetic Target #4: (because the answer key should have all four…)



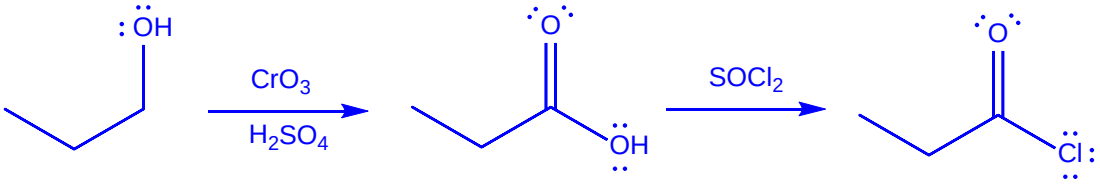
Synthesis:

Retrosynthetic analysis (aka "The Plan"):

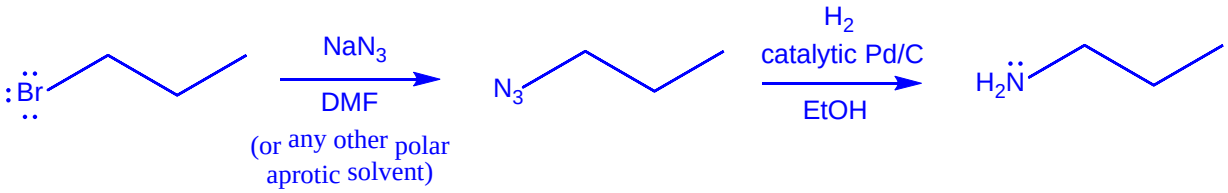


Synthetic Proposal:

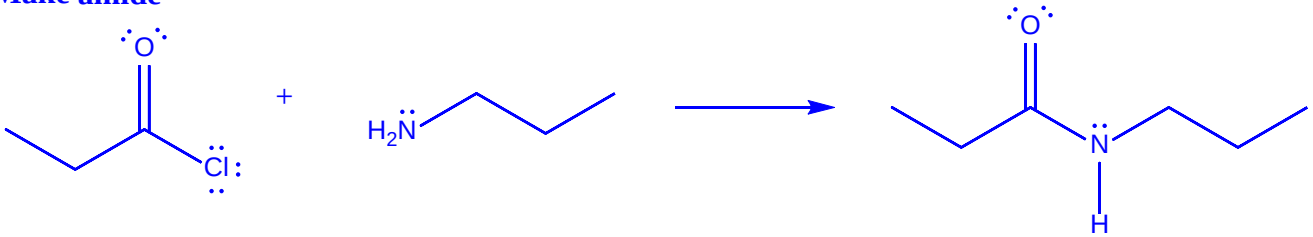
Make acid chloride



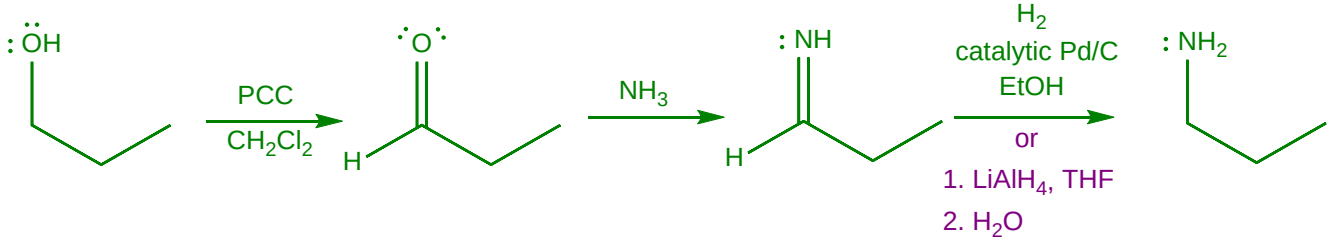
Make amine



Make amide

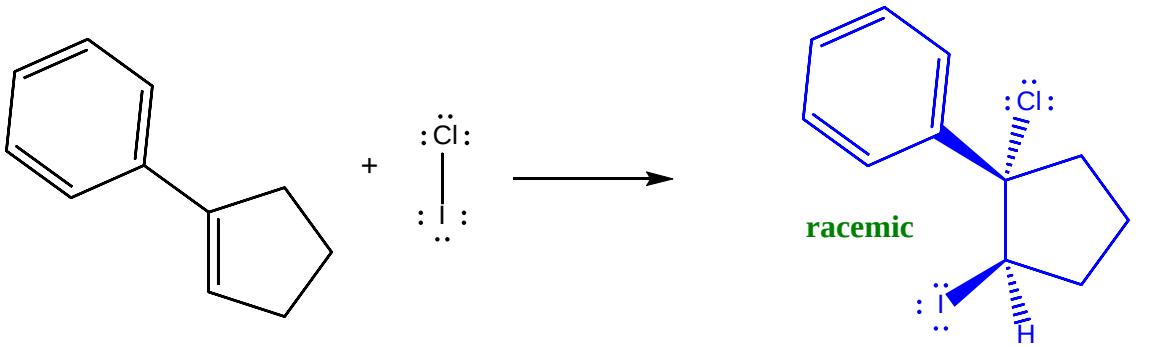


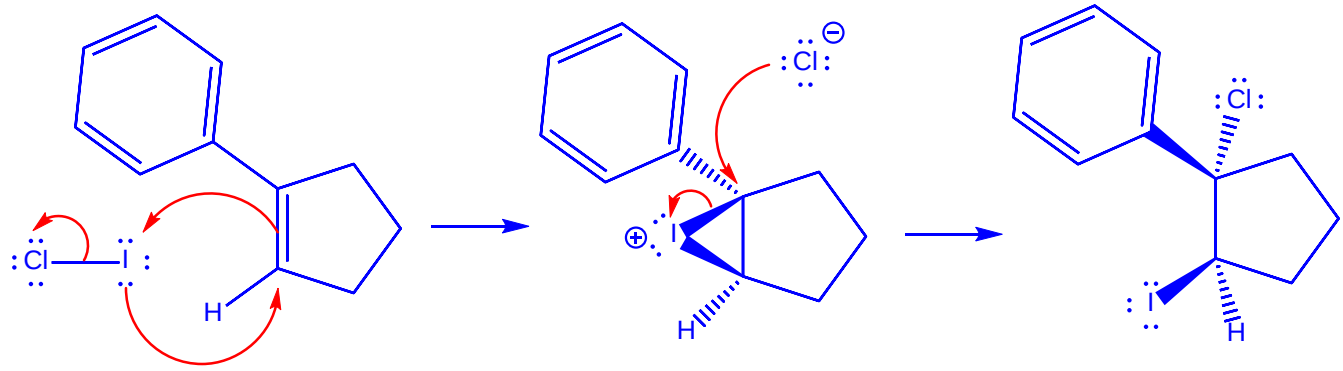
Alternative route to make amine from 1-propanol (instead of 1-bromopropane)



Name: _____ Student Number: _____

7. Show the mechanism for the reaction below and draw the major organic product. **[5 marks]** Clearly show any relevant regiochemistry and/or stereochemistry in the product.





The nucleophilic alkene attacks the more electronegative end of ICl ($I^{\delta+}$ rather than $Cl^{\delta-}$). This gives the iodonium ion which forces Cl^- to attack from the opposite side, giving exclusively anti addition.
Cl^- attacks the 3° carbon atom because it is more electrophilic than the 2° carbon atom. This is consistent with the idea that the resonance structure with a 3° carbocation is a greater contributor to the average structure than the one with a 2° carbocation.

8. What was the most interesting and/or useful thing you learned in CHEM 2600? **[1 mark]**

…AND THAT'S ALL FOR CHEM 2600.
HAVE A GREAT SUMMER!

DATA SHEET/SCRAP PAPER

CHEM 1000 Standard Periodic Table

1												13	14	15	16	17	18
1.0079 **H** 1	2																4.0026 **He** 2
6.941 **Li** 3	9.0122 **Be** 4											10.811 **B** 5	12.011 **C** 6	14.0067 **N** 7	15.9994 **O** 8	18.9984 **F** 9	20.1797 **Ne** 10
22.9898 **Na** 11	24.3050 **Mg** 12	3	4	5	6	7	8	9	10	11	12	26.9815 **Al** 13	28.0855 **Si** 14	30.9738 **P** 15	32.066 **S** 16	35.4527 **Cl** 17	39.948 **Ar** 18
39.0983 **K** 19	40.078 **Ca** 20	44.9559 **Sc** 21	47.88 **Ti** 22	50.9415 **V** 23	51.9961 **Cr** 24	54.9380 **Mn** 25	55.847 **Fe** 26	58.9332 **Co** 27	58.693 **Ni** 28	63.546 **Cu** 29	65.39 **Zn** 30	69.723 **Ga** 31	72.61 **Ge** 32	74.9216 **As** 33	78.96 **Se** 34	79.904 **Br** 35	83.80 **Kr** 36
85.4678 **Rb** 37	87.62 **Sr** 38	88.9059 **Y** 39	91.224 **Zr** 40	92.9064 **Nb** 41	95.94 **Mo** 42	(98) **Tc** 43	101.07 **Ru** 44	102.906 **Rh** 45	106.42 **Pd** 46	107.868 **Ag** 47	112.411 **Cd** 48	114.82 **In** 49	118.710 **Sn** 50	121.757 **Sb** 51	127.60 **Te** 52	126.905 **I** 53	131.29 **Xe** 54
132.905 **Cs** 55	137.327 **Ba** 56	**La-Lu**	178.49 **Hf** 72	180.948 **Ta** 73	183.85 **W** 74	186.207 **Re** 75	190.2 **Os** 76	192.22 **Ir** 77	195.08 **Pt** 78	196.967 **Au** 79	200.59 **Hg** 80	204.383 **Tl** 81	207.19 **Pb** 82	208.980 **Bi** 83	(210) **Po** 84	(210) **At** 85	(222) **Rn** 86
(223) **Fr** 87	226.025 **Ra** 88	**Ac-Lr**	(265) **Rf** 104	(268) **Db** 105	(271) **Sg** 106	(270) **Bh** 107	(277) **Hs** 108	(276) **Mt** 109	(281) **Ds** 110	(280) **Rg** 111	(285) **Cn** 112	(284) **Nh** 113	(289) **Fl** 114	(288) **Mc** 115	(293) **Lv** 116	(294) **Ts** 117	(294) **Og** 118

138.906 **La** 57	140.115 **Ce** 58	140.908 **Pr** 59	144.24 **Nd** 60	(145) **Pm** 61	150.36 **Sm** 62	151.965 **Eu** 63	157.25 **Gd** 64	158.925 **Tb** 65	162.50 **Dy** 66	164.930 **Ho** 67	167.26 **Er** 68	168.934 **Tm** 69	173.04 **Yb** 70	174.967 **Lu** 71
227.028 **Ac** 89	232.038 **Th** 90	231.036 **Pa** 91	238.029 **U** 92	237.048 **Np** 93	(240) **Pu** 94	(243) **Am** 95	(247) **Cm** 96	(247) **Bk** 97	(251) **Cf** 98	(252) **Es** 99	(257) **Fm** 100	(258) **Md** 101	(259) **No** 102	(262) **Lr** 103

Developed by Prof. R. T. Boeré (updated 2016)