Winter 2024 **Chemistry 2500 Final Exam** ____/98 marks

Confidentiality Agreement:
I agree not to discuss (or in any other way divulge) the contents of this exam with (or in the presence of) any CHEM 2500 student who has yet to write it. I understand that breaking this agreement would constitute academic misconduct. The minimum penalty would be a mark of 0/98 on this exam.

Signature: _____ Date: _____

1) Please read the test carefully before starting. It has 12 pages of questions.
2) You have been given a data sheet with a periodic table. This page does not have a QR code, so nothing written on this sheet of paper will be graded. If you wish to do rough work that you might want a grader to be able to see, use the back of any page of the test.
3) 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.
4) You **may** use a molecular model kit. You may not have written materials in your model kit.
5) You may **not** use a calculator or any other electronic device.
6) **DO NOT WRITE ON ANY QR CODE!!!** Work on pages without a QR code will not be graded.
7) If your work is not legible, it will be given a mark of zero. For full credit, explanations must be complete. In many cases, complete explanations include drawing relevant structures. If delocalization of electrons is invoked, the relevant resonance structures must be drawn.
8) Marks will be deducted for incorrect information added to an otherwise correct answer.
9) You have 3 hours to complete this test.

Question Breakdown

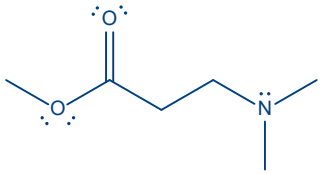
Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Total
/ 8	/ 2	/ 2	/ 2	/ 2	/ 11	/ 10	/ 8	/ 6	/ 8	/ 10	/ 16	/ 6	/ 6	/ 1	/ 98

1. All your answers to the questions below should have the molecular formula $C_6H_{13}NO_2$. **[8 marks]**

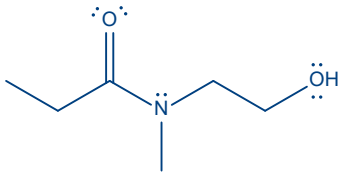
   You may draw your answers using either line-bond notation or expanded notation; however, you must draw reasonable bond angles and show all lone pairs.

There are MANY viable answers to each of these questions. A sample answer has been provided for each.

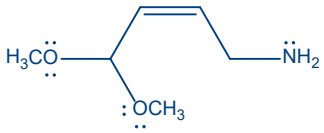
(a) Draw an ester. *[2 marks]*



(b) Draw an amide. *[2 marks]*



(c) Draw an alkene whose configuration is Z. *[2 marks]*



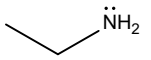
(d) Draw a molecule capable of hydrogen bonding with another molecule of the same compound. *[2 marks]*



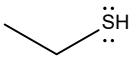
2. Name a functional group which **cannot** be present in any compound with the molecular formula $C_6H_{13}NO_2$ **and** which does not contain any elements other than C, H, N and/or O. Draw an example of a molecule containing this functional group. **[2 marks]**

   Viable answers are alkyne, nitrile, anhydride or aromatic ring (arene). $C_6H_{13}NO_2$ only has one degree of unsaturation, so it cannot contain a triple bond ($C \equiv C$ or $C \equiv N$) more than one double bond ($O = C - O - C = O$) or a combination of ring and double bonds (as in a benzene ring).

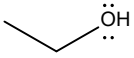
3. Rank the following compounds from weakest acid to strongest acid: **[2 marks]**



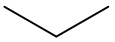
A



B



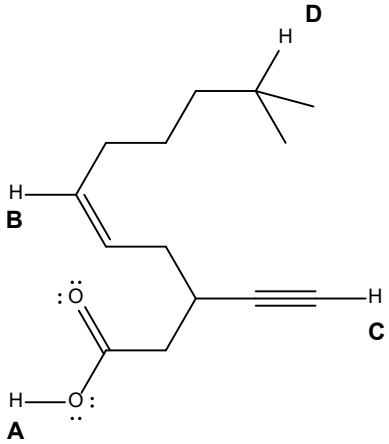
C



D

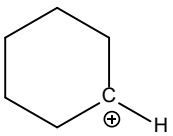
weakest _____**D**_____ _____**A**_____ _____**C**_____ _____**B**_____ strongest

4. Rank the hydrogen atoms labeled on the diagram below from least acidic to most acidic: **[2 marks]**

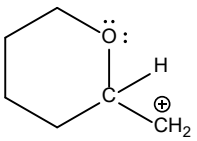


least acidic _____**D**_____ _____**B**_____ _____**C**_____ _____**A**_____ most acidic

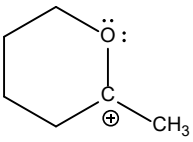
5. Rank the following carbocations from least to most stable: **[2 marks]**



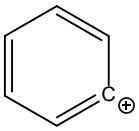
A



B



C



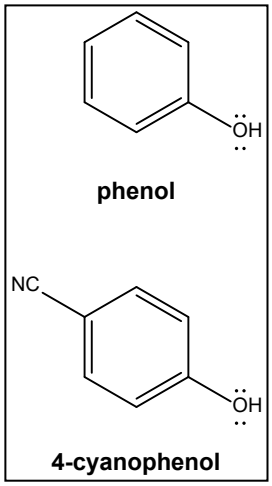
D

least stable _____**D**_____ _____**B**_____ _____**A**_____ _____**C**_____ most stable

6. The pK_a of phenol is 10. The pK_a of 4-cyanophenol is 8. **[11 marks]**

(a) Which of these two compounds is the stronger acid? *[1 mark]*

4-cyanophenol



(b) Which of these two compounds can be deprotonated by $NaOH$? *[2 marks]*
In other words, "reaction with $NaOH$ will be product-favoured for…"

Circle your choice.

i. phenol only
ii. 4-cyanophenol only
iii. both compounds
iv. neither compound

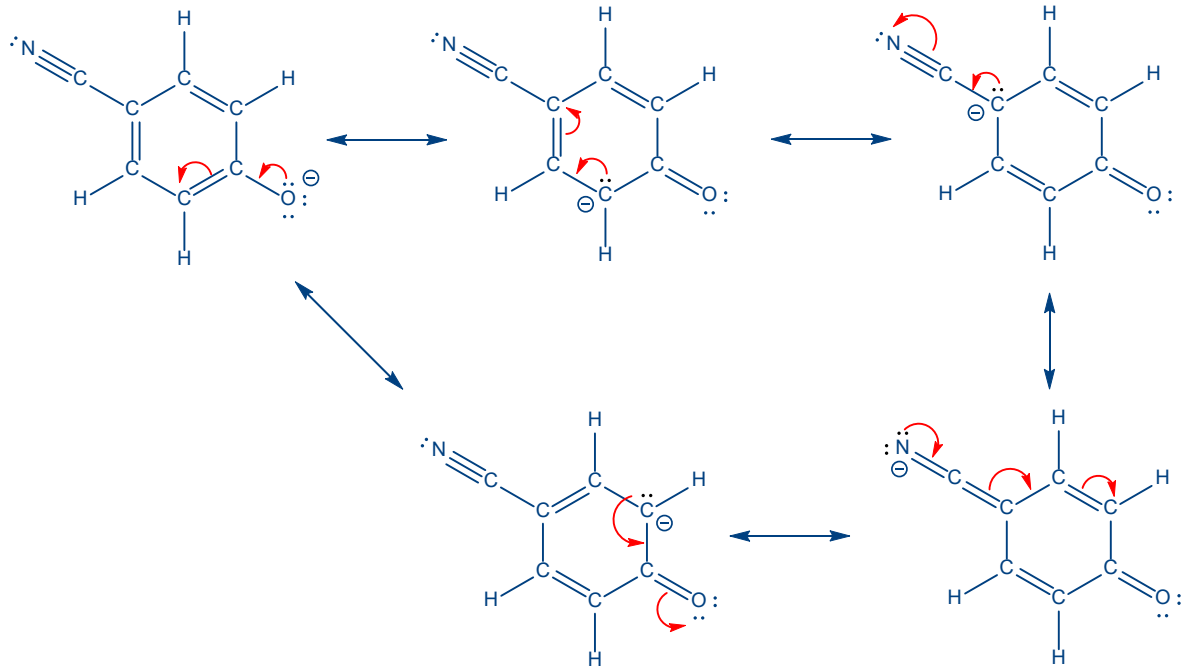
(c) Which of these two compounds can be deprotonated by water? *[2 marks]*
In other words, "reaction with water will be product-favoured for…"

Circle your choice.

i. phenol only
ii. 4-cyanophenol only
iii. both compounds
iv. neither compound

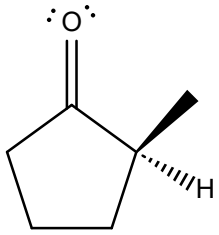
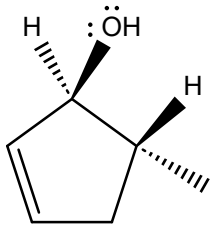
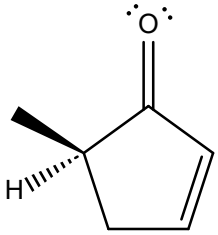
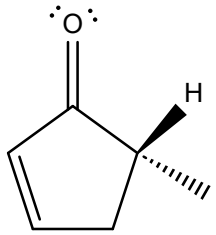
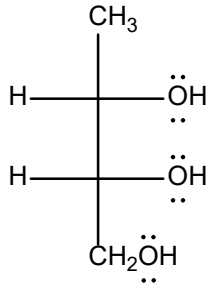
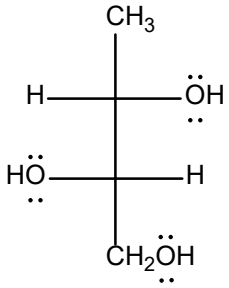
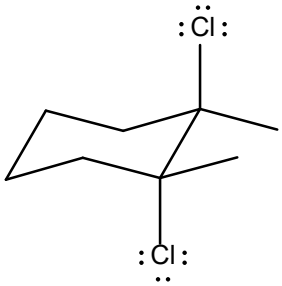
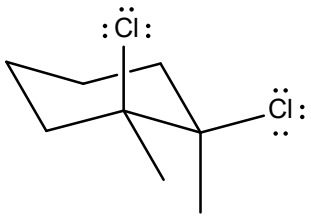
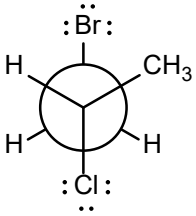
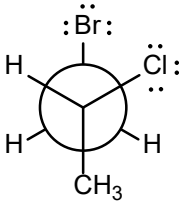
(d) Draw all valid resonance structures for the **conjugate base** of the stronger acid. Explain what these resonance structures show that can be used to justify why this is the stronger of the two acids. *[6 marks]*

4-cyanophenol is the stronger acid because is has the more stable conjugate base. This is because the negative charge of the conjugate base is delocalized across more atoms, as shown in the resonance structures below. (In phenoxide, it is not possible to delocalize the negative charge onto a nitrogen atom in the same way as you can for 4-cyanophenoxide.)



7. Using the appropriate letter or letters, identify the relationship between each of the following pairs of molecules. If more than one term applies, list all the corresponding letters. **[10 marks]**

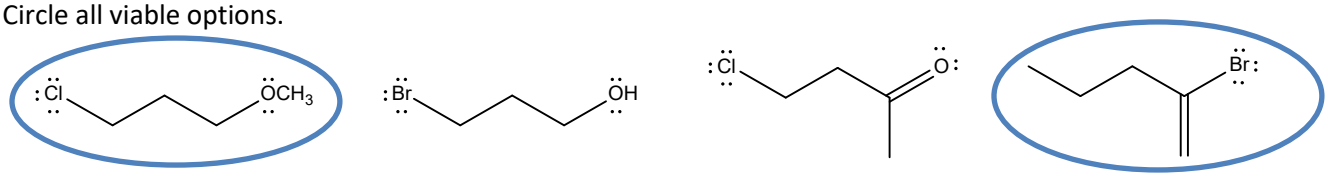
A = stereoisomers
B = constitutional isomers
C = conformers
D = diastereomers
E = enantiomers
F = identical molecules
G = none of the above

			relationship
	and		B
	and		F
	and		A,D
	and		A,D
	and		A,E

8. **[8 marks]**

(a) From which of the following compounds is it possible to prepare a Grignard reagent? *[2 marks]*

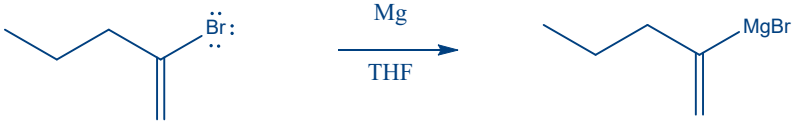
Circle all viable options.



(b) Choose one compound circled in part (a), and write a chemical equation showing the reagent(s) and solvent(s) necessary to convert it into a Grignard reagent as well as the structure of the Grignard reagent produced. *[3 marks]*

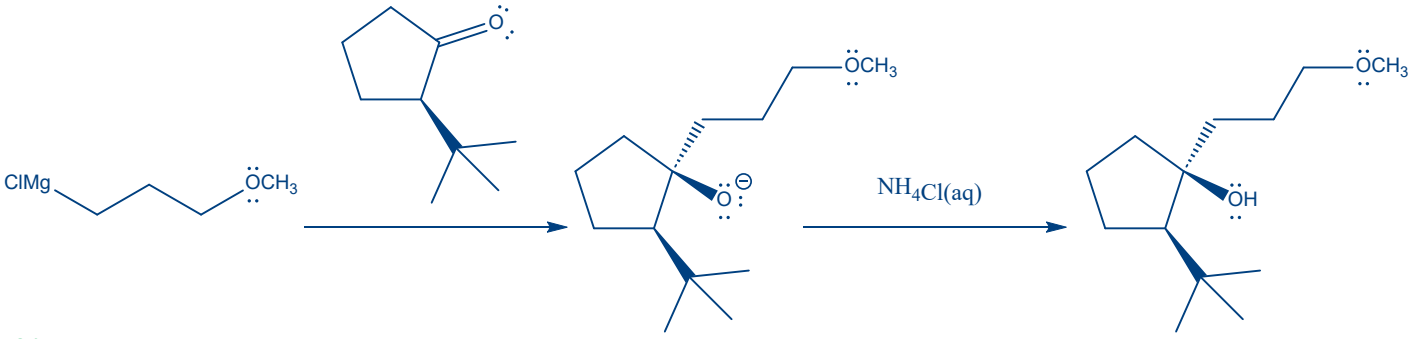


or

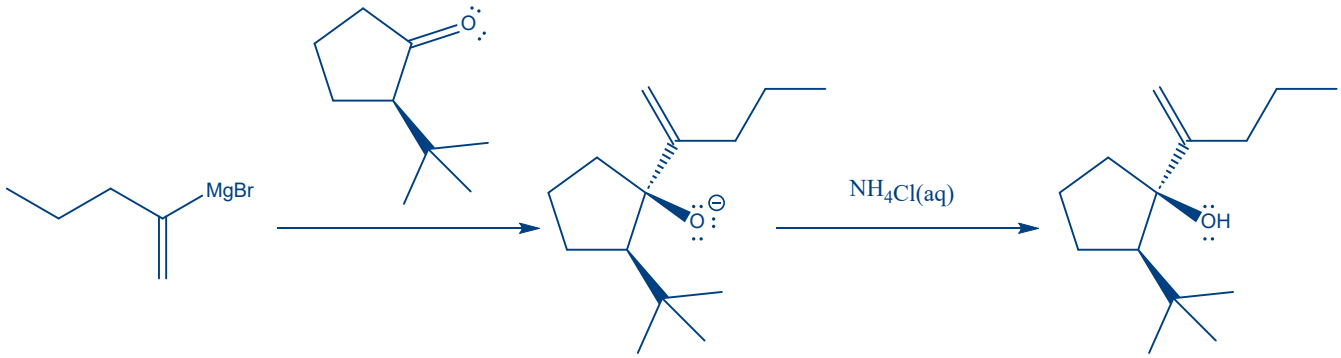


Solvent may be any ethereal solvent (THF, Et_2O, etc.)

(c) Draw the major product obtained when your Grignard reagent from part (b) reacts with (*R*)-2-*tert*-butylcyclopentanone both before and after mildly acidic aqueous work-up: *[3 marks]*



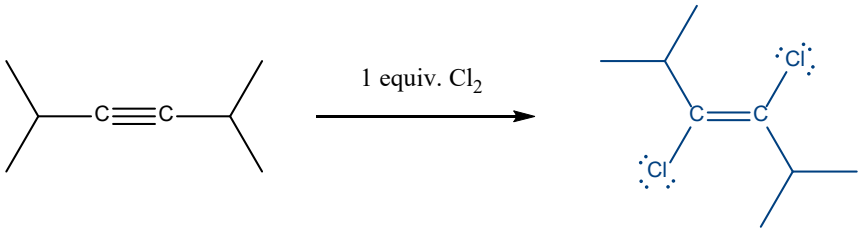
or



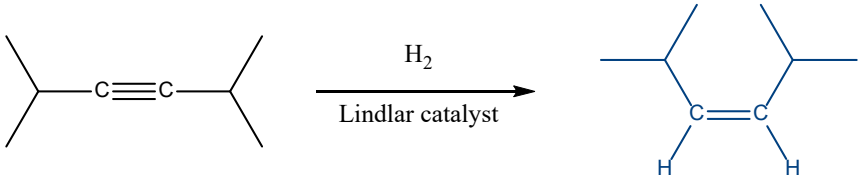
9. Draw the major organic product of each for the following reactions. "Equiv." stands for "equivalents" and refers to the number of moles of reagent added per mole of starting material. If the number of equivalents of a reagent is not specified, assume that it is available in excess. **[6 marks]**

Clearly show any relevant stereochemistry.

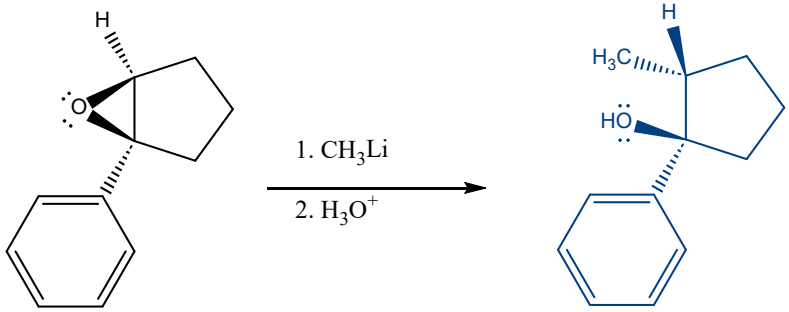
(a)



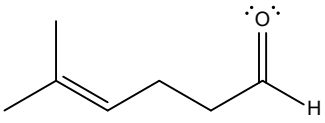
(b)



(c)



10. Consider Compound X, shown below. **[8 marks]**

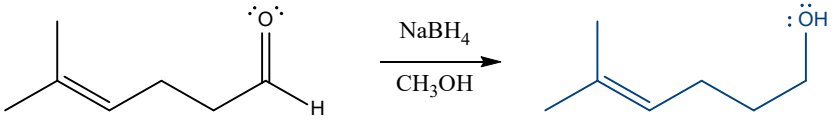


Compound X

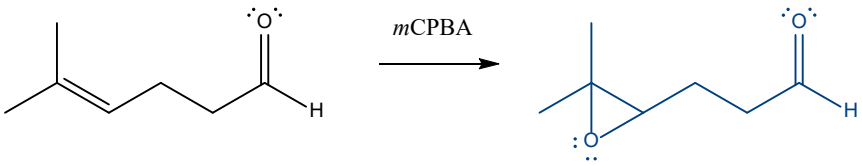
(a) Name Compound X according to IUPAC naming conventions. *[2 marks]*

5-methylhex-4-enal

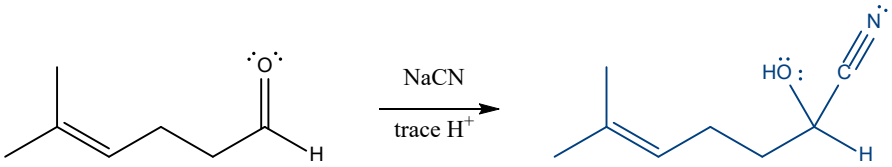
(b) Draw the product obtained when Compound X is reacted with sodium borohydride in methanol. *[2 marks]*



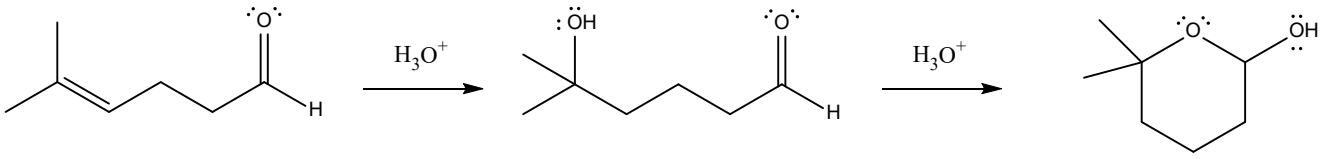
(c) Draw the product obtained when Compound X is reacted with *meta*-chloroperoxybenzoic acid. *[2 marks]*



(d) Draw the product obtained when Compound X is reacted with sodium cyanide and trace acid. *[2 marks]*



11. Something unexpected happens when you add Compound X to aqueous sulfuric acid. You expected to make Compound Y; however, you find that Compound Y reacts with aqueous acid to give Compound Z! **[10 marks]**



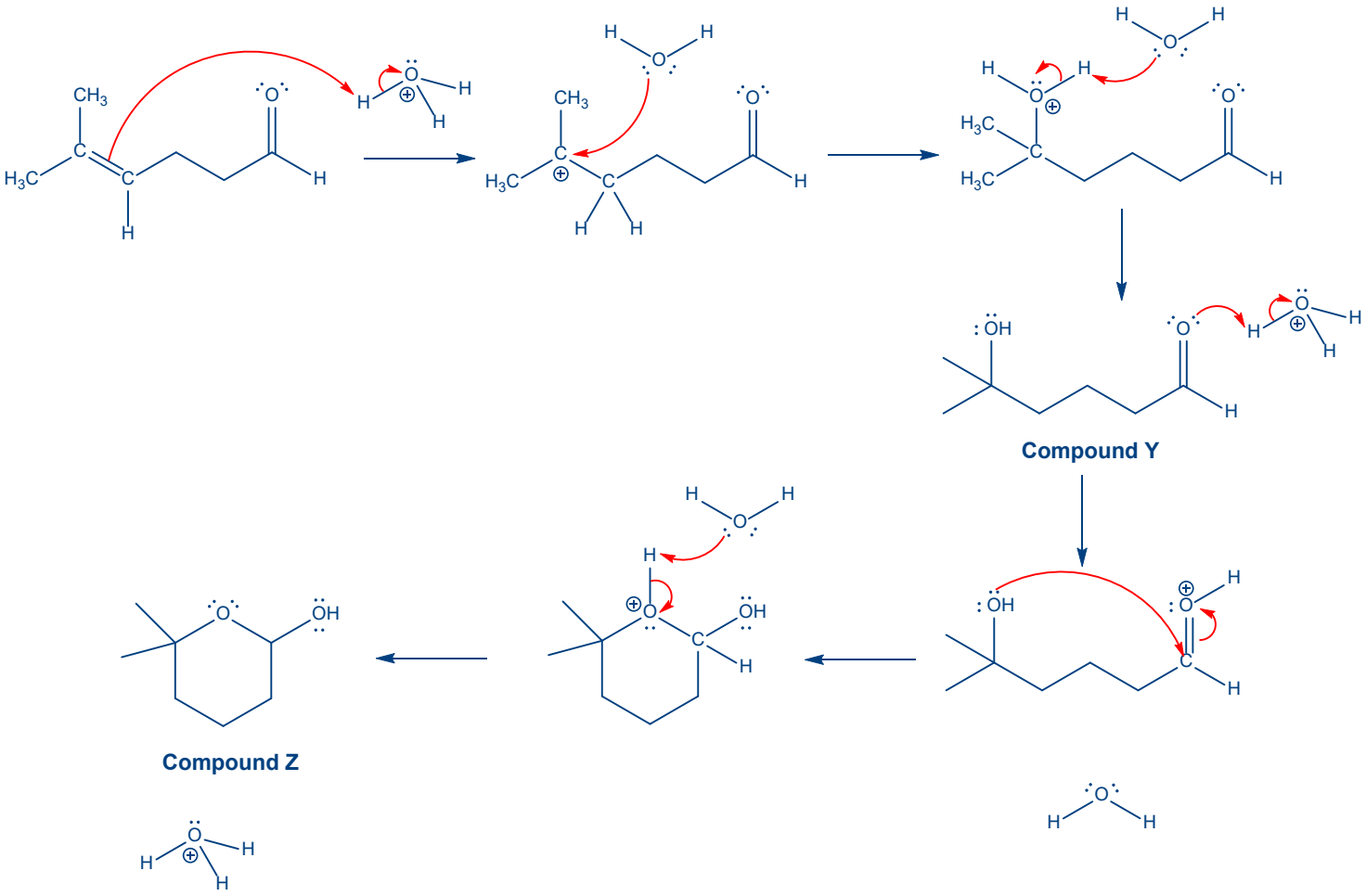
Compound X **Compound Y** **Compound Z**

(a) Propose a valid mechanism for the acid-catalyzed reaction giving Compound Y from Compound X. *[5 marks]*

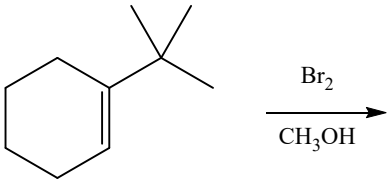
(b) Propose a valid mechanism for the acid-catalyzed reaction giving Compound Z from Compound Y. *[5 marks]*

Use curved arrows to show the movement of electrons in each step, and draw all products of each step.

You may assume the presence of as many water molecules and as much acid as you need.



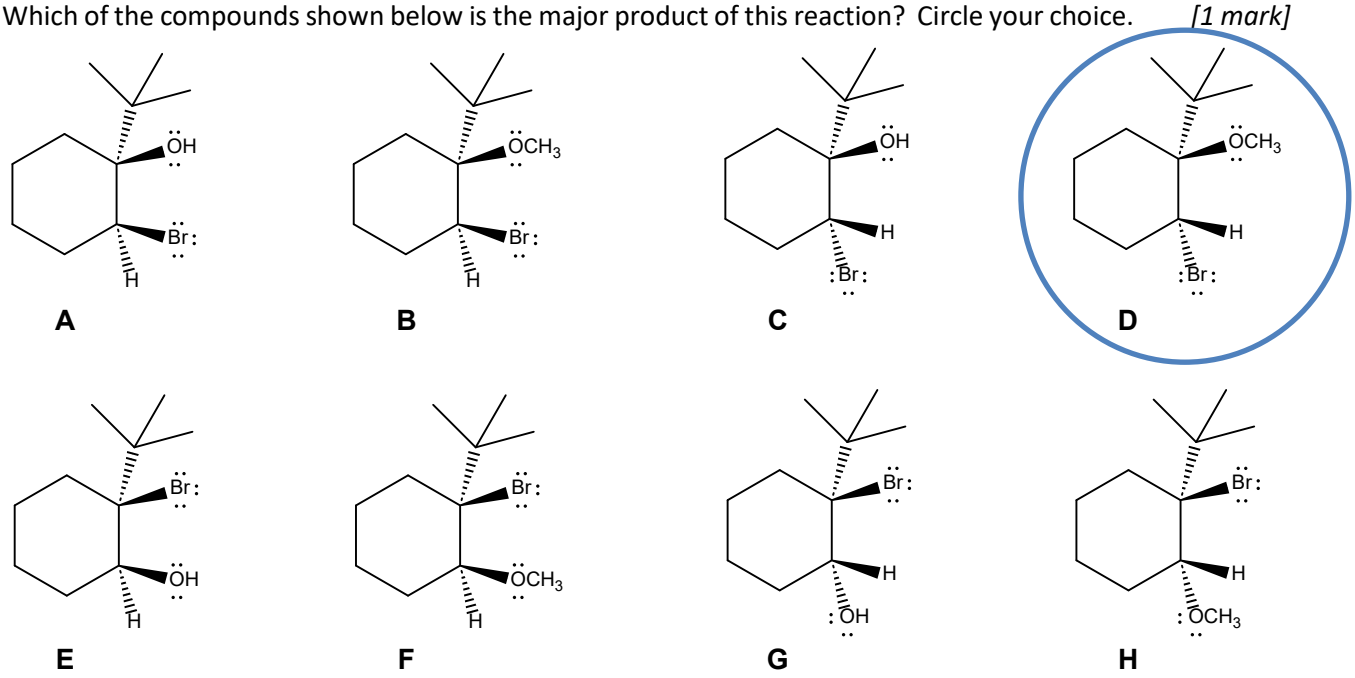
12. Consider the reaction conditions shown below. **[16 marks]**



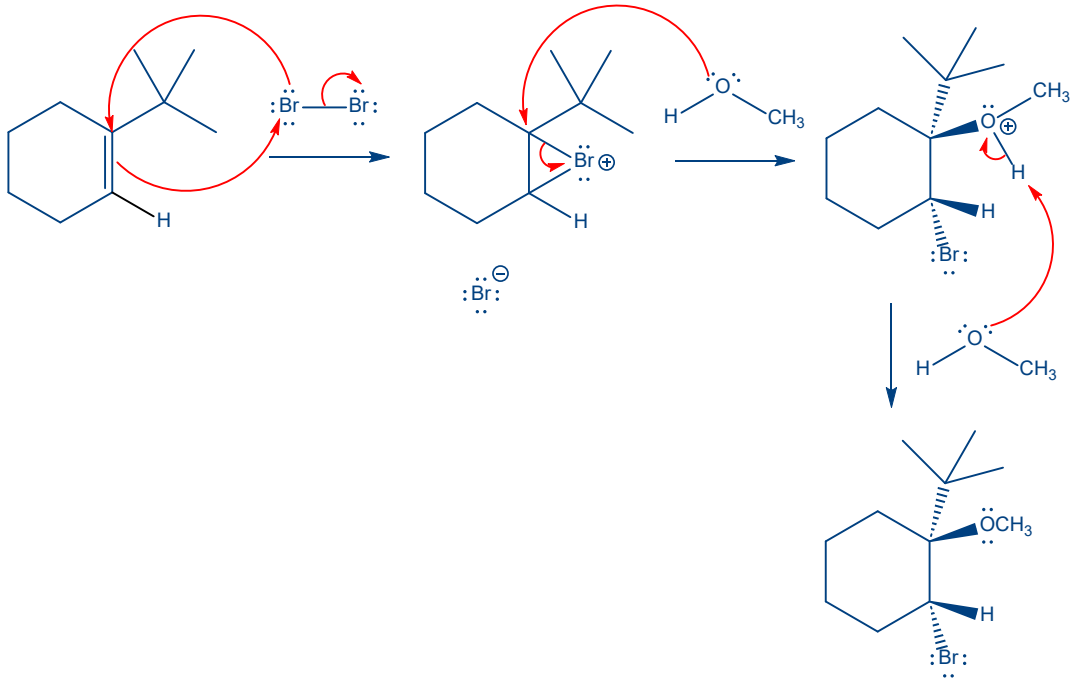
(a) Name the starting material drawn above according to IUPAC naming conventions. *[1 mark]*

1-*tert*-butylcyclohexene *or* 1-*t*-butylcyclohexene

(b) Which of the compounds shown below is the major product of this reaction? Circle your choice. *[1 mark]*



(c) Justify your answer to part (b) by drawing the mechanism for this reaction. *[5 marks]*

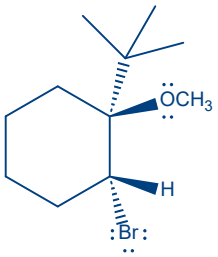


12. *…continued from previous page*

(d) Draw your answer to part (b) in the space below. This isn't worth any marks. It's just to make your life easier for the rest of this question. If you change your mind about part (b) later, DO NOT take the time to redo this page. Parts (e) onward will be graded based on the structure you draw here. If you don't have an answer to part (b), pick one of the eight molecules and draw it here.

To make Susan's life easier, please also write the letter that was provided below your answer to part (b).

D

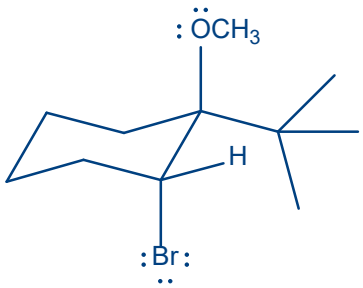


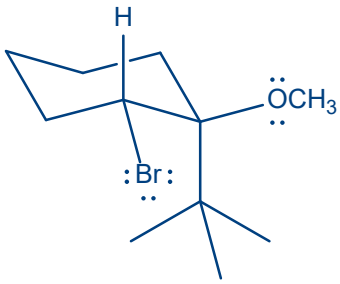
(e) On your answer to part (d), assign the configuration of each chirality center as *R* or *S*. *[4 marks]*

For full marks, you must show the priority numbers you used to assign each configuration and it must be clear what part of the molecule is being described as R or S.

Possible product	Configuration of top chiral center	Configuration of bottom chiral center
A	*S*	*S*
B	*S*	*S*
C	*S*	*R*
D	*S*	*R*
E	*S*	*S*
F	*S*	*S*
G	*S*	*R*
H	*S*	*R*

(f) In the space below, draw the two possible chair conformers for your answer to part (d). Clearly label which of the two chair conformers is expected to be the major one, and briefly justify your choice. *[5 marks]*

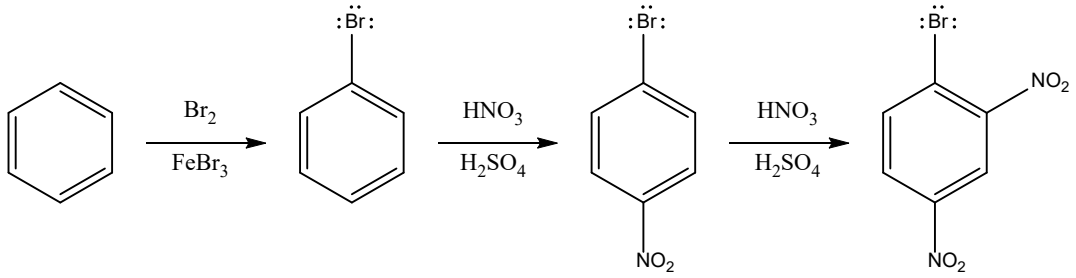




major conformer
t-butyl group is VERY bulky, so it is strongly favoured for it to occupy an equatorial site.
(This is true even though it puts two smaller groups in axial sites. It is more important to put the very large group where there is space for it.)

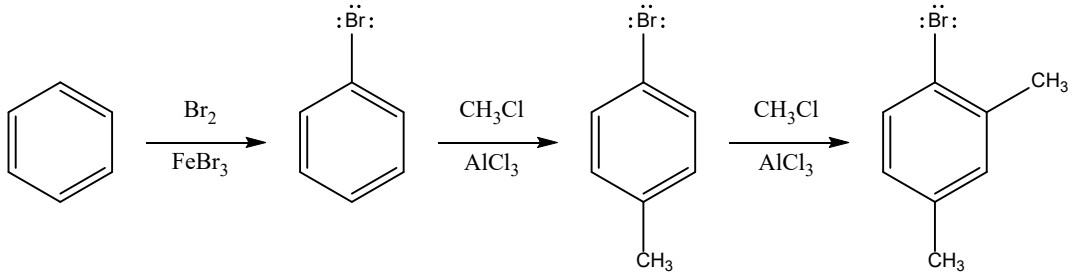
13. Consider the two synthetic proposals below. One should work as written. The other will not. **[6 marks]**

Synthetic Proposal A



Product A

Synthetic Proposal B



Product B

(a) Name Product A according to IUPAC naming conventions. *[2 marks]*

1-bromo-2,4-dinitrobenzene

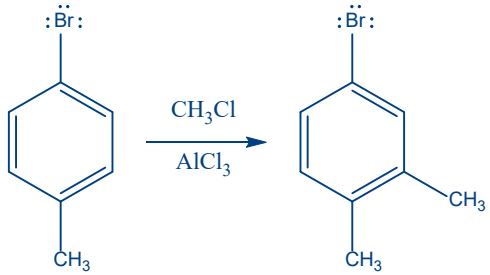
(b) Which of the two proposals is expected to work as written? *[1 mark]*

A

(c) Justify your answer to part (b) by explaining why the **<u>other</u>** proposal will **<u>not</u>** work as written. *[3 marks]*

For full marks, your answer must both identify the problem(s) and show what will happen instead.

Synthetic Proposal B will not work as written. The last step cannot possibly work as shown because CH_3 is an electron-donating group and a strong ortho/para-director. As such, if 1-bromo-4-methylbenzene reacted with CH_3Cl and $AlCl_3$, the new methyl group would add ortho to the existing methyl group (and not ortho to the bromine atom as shown in the proposal):

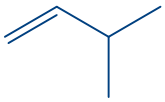


A further problem with Synthetic Proposal B is that Friedel-Crafts reactions on electron-deficient aromatic rings are not favourable. So, since Br is inductively electron withdrawing and deactivates the ring, it's likely that bromobenzene simply wouldn't react with $CH_3Cl/AlCl_3$ in the second step. NO_2^+ is a more reactive electrophile, so this is less likely to be a problem for Synthetic Proposal A.

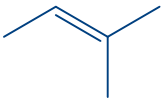
14. Suppose you wish to prepare 3-methylbutan-2-ol from an alkene. **[6 marks]**

(a) Draw the **<u>two</u>** alkenes you could reasonably use as starting materials for this synthesis. *[2 marks]*

Label one of your alkenes as "B" and the other one as "C".



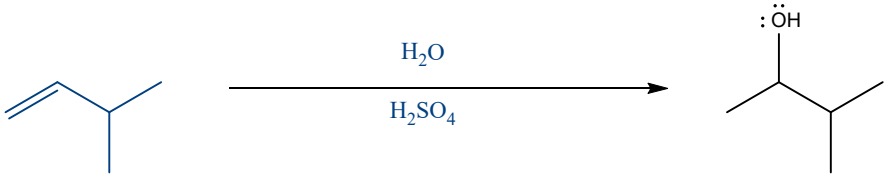
B



C

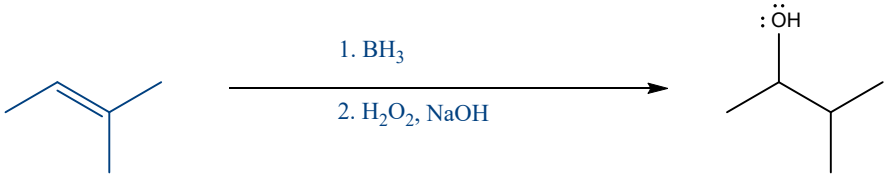
(b) Write an equation showing the reaction of alkene "B" to give 3-methylbutan-2-ol. *[2 marks]*

Your answer must clearly show what reagent(s) are required to convert "B" into 3-methylbutan-2-ol.



(c) Write an equation showing the reaction of alkene "C" to give 3-methylbutan-2-ol. *[2 marks]*

Your answer must clearly show what reagent(s) are required to convert "C" into 3-methylbutan-2-ol.



15. What was the most useful and/or interesting thing you learned in CHEM 2500? **[1 mark]**

…AND THAT'S ALL FOR CHEM 2500.

HAVE A GREAT SUMMER!