UNIVERSITY OF CALGARY

FACULTY OF SCIENCE

FINAL EXAMINATION

CHEMISTRY 353

Version 1

April 26th, 2019 **Time: 3 Hours**

READ THE INSTRUCTIONS CAREFULLY

PLEASE WRITE YOUR **NAME** & **STUDENT I.D. NUMBER** ON ***BOTH*** **YOUR BLUE ANSWER BOOKLET** AND **COMPUTER ANSWER SHEET**.
ENTER **VERSION NUMBER 1** ON THE **COMPUTER ANSWER SHEET**

The examination consists of Parts **1 - 10**, each of which should be attempted. Note that some Parts provide you with a choice of questions, *e.g*. answer 5 out of 6. These will be graded in order the answers appear until the required number have been completed, ***regardless*** of whether they are right or wrong.

Parts **1 - 6** will be computer graded, and Parts **7 - 10** are to be answered in the blue answer booklet. Parts **1 - 6** consist of a series of multiple choice questions numbered **1 - 49** which are to be answered on your optical score answer sheet. Indicate your answer by blackening out the appropriate space, A, B, C, D or E on the answer sheet. Use a pencil only and ***not ink***. In some cases it is required that you indicate ***multiple*** items for a complete and/or correct answer by blackening out more than one space. In some other cases more than five options are available and some of these also require more than one space to be blackened out. For an example, an option specified as AB requires that you blacken out ***both*** space A and space B. Part marks may be awarded in some of the questions. Incorrect answers must be erased ***cleanly***.

A periodic table with atomic numbers and atomic weights and tables of spectroscopic data are provided at the end of the examination paper. **No other resources are allowed**.

Molecular models and calculators are permitted, ***but NOT programmable calculators***.

Absolutely no other electronic devices are allowed.

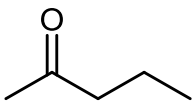
12% PART 1: RELATIVE PROPERTIES

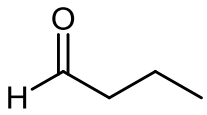
ANSWER ANY EIGHT (8) OF THE TEN (10) QUESTIONS 1-10.

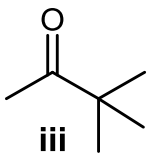
Arrange the items in questions 1-10 in DECREASING ORDER (*i.e.* greatest, most *etc*. *first*) with respect to the indicated property. Use the following code to indicate your answers in the box provided:

A	**i > ii > iii**	**D**	**ii > iii > i**
B	**i > iii > ii**	**E**	**iii > i > ii**
C	**ii > i > iii**	**AB**	**iii > ii > i**

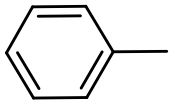
1. The relative reactivity of each of following towards sodium borohydride:

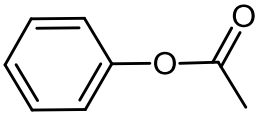

i

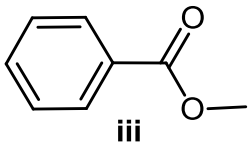

ii


iii

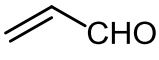
2. The relative rate of reaction of $(CH_3)_3CCl$ / $AlCl_3$ with each of the following:

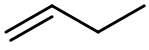

i

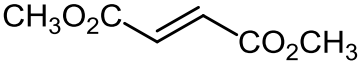

ii


iii

3. The relative reactivity of each of the following towards 1,3-butadiene:


i

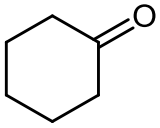

ii

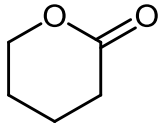

iii

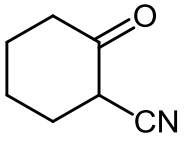
4. The relative reactivity of each of the following towards HCl:

$H_2C{=}CHCH{=}CH_2$ **i** $H_2C{=}CH_2$ **ii** $CH_3CH_2CH{=}CH_2$ **iii**

5. The relative acidity of the most acidic hydrogen in each of the following:


i

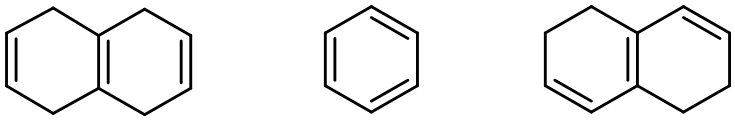

ii


iii

Use the following code to indicate your answers in the box provided:

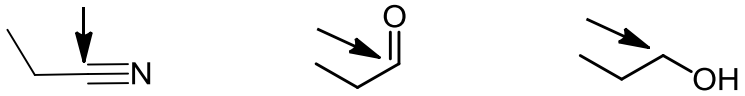
A	**i > ii > iii**	**D**	**ii > iii > i**
B	**i > iii > ii**	**E**	**iii > i > ii**
C	**ii > i > iii**	**AB**	**iii > ii > i**

6. The resonance energies of each of the following:



i **ii** **iii**

7. The relative oxidation state of the C atom indicated in each of the following:



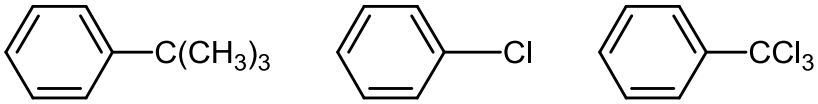
i **ii** **iii**

8. The relative yields of a methyl ketone from the reactions of each of the following with (1) BH_3/THF then (2) aq. H_2O_2 / NaOH:

$CH_3C{\equiv}CCH(CH_3)_2$ $CH_3C{\equiv}CCH_2CH_3$ $CH_3C{\equiv}CCH_3$

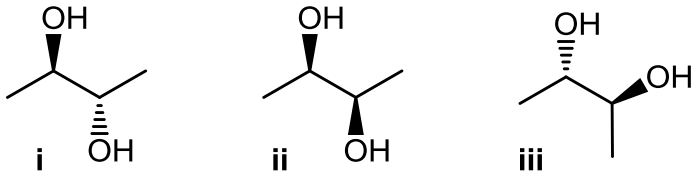
i **ii** **iii**

9. The % yield of the *para* product produced by the reaction of Br_2 / $FeBr_3$ with each of the following:



i **ii** **iii**

10. The specific rotations of each of the following molecules given that (2R,3R)-butan-2,3-diol has an $[\alpha]_D = -13.2^o$:

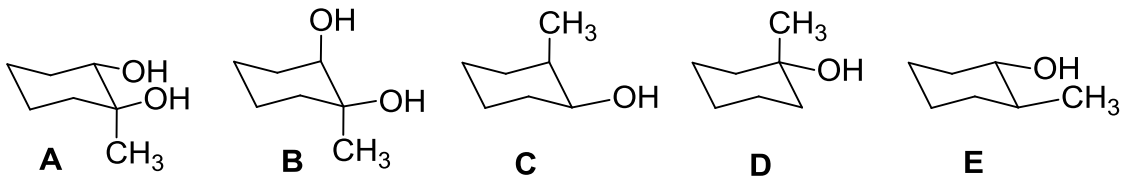


8 % PART 2: STRUCTURE AND PROPERTIES

ANSWER ANY EIGHT (8) OF THE NINE (9) QUESTIONS 11-19.

IN SOME CASES more than one answer may be correct and ALL compounds that apply MUST be selected for full credit.

SET 1



Answer questions 11-15 by selecting the compounds from SET 1 above.

11. Which compound(s) is (are) optically inactive ?

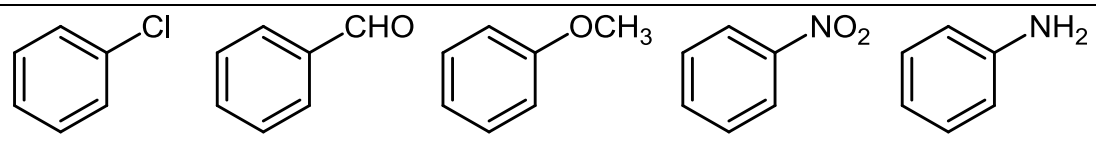
12. Which compound is the **major product** formed from the reaction of 1-methylcyclohexene with (1) BH_3 then (2) aq. H_2O_2 / NaOH ?

13. Which compound is the **major product** formed from the reaction of 1-methylcyclohexene with aqueous H_2SO_4 ?

14. Which compound is the **major product** formed from the reaction of 1-methylcyclohexene with (1) CH_3CO_3H then (2) aq. NaOH ?

15. Which compound is the **major product** formed from the reaction of 1-methylcyclohexene with $KMnO_4$, aq. NaOH, 0^oC ?

SET 2



Answer questions 16-19 about electrophilic aromatic substitution by selecting a compound from SET 2 above

16. Which compound is the **most** activated compared to benzene ?

17. Which compound is the **most** deactivated compared to benzene ?

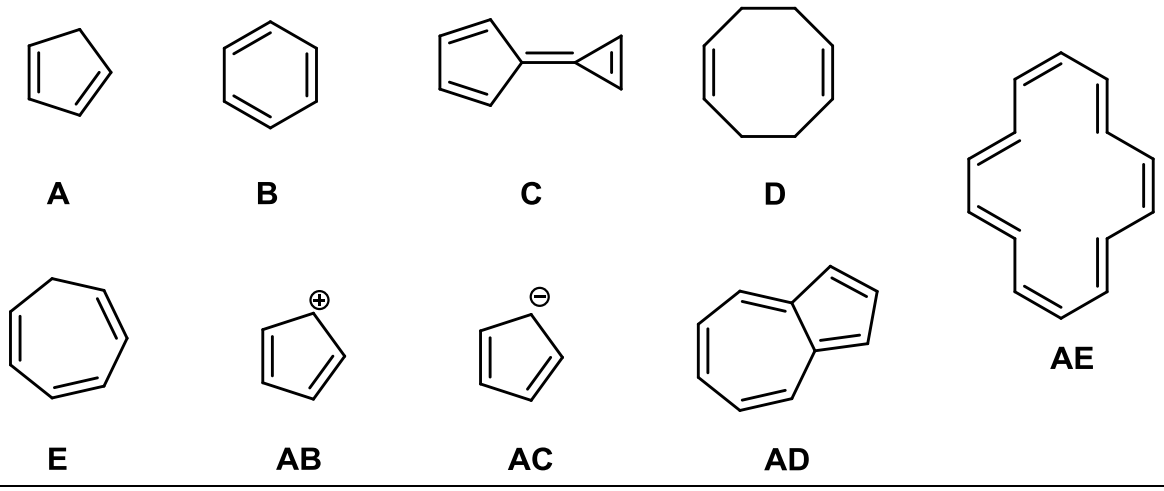
18. Which **compound(s) is/are** deactivated and direct *meta* ?

19. Which **compound(s)** undergo successful acylation with $CH_3C(=O)Cl$ / $AlCl_3$?

9% PART 3: AROMATICITY AND RESONANCE

ANSWER ANY NINE (9) OF THE TEN (10) QUESTIONS 20 - 29.

SET 3:



Answer questions 20-24 by selecting a SINGLE compound from SET 3 above.

20. Non-aromatic as drawn but has an aromatic conjugate base.

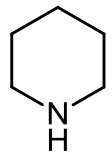
21. Non-aromatic as drawn but has an antiaromatic conjugate base.

22. A diene with no resonance energy stabilization.

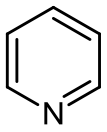
23. The compound with the largest "n" value in the Huckel rule

24. An aromatic triene.

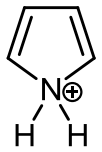
SET 4:



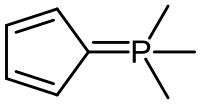
A



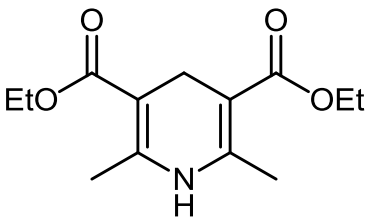
B



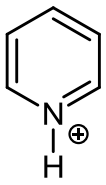
C



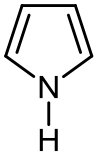
D



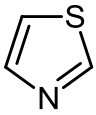
AE



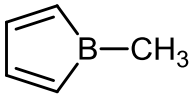
E



AB



AC



AD

Answer questions 25-29 by selecting a <u>SINGLE compound</u> from SET 4 above.

25. Select the compound that contains the **most** acidic proton

26. Select the compound with the **most** basic nitrogen atom

27. Select the compound **most** likely to donate a hydride atom

28. Non aromatic as drawn but has an important aromatic resonance structure

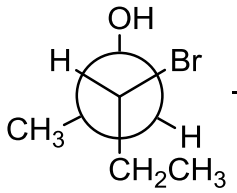
29. An antiaromatic compound.

16% PART 4: STARTING MATERIALS AND PRODUCTS OF SYNTHESIS

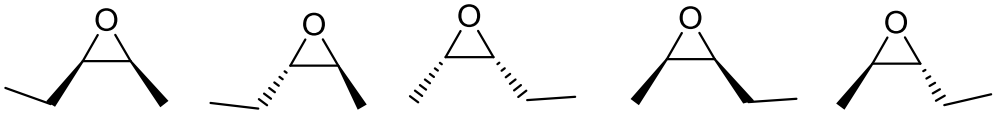
ANSWER ANY EIGHT (8) OF THE NINE (9) QUESTIONS 30-38.

For each of the questions 30 - 38 identify the product(s) obtained or starting material(s) required in order to best complete each of the reaction sequences shown by selecting from the list provided.

30.



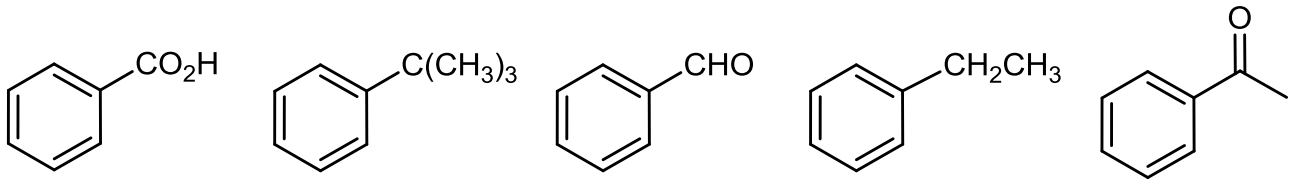
Na_2CO_3 → ?



A **B** **C** **D** **E**

31.

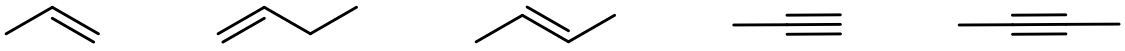
? → 1) $(CH_3)_3CCl / AlCl_3$; 2) $KMnO_4 / H_3O^+$ / heat → CO_2H



A **B** **C** **D** **E**

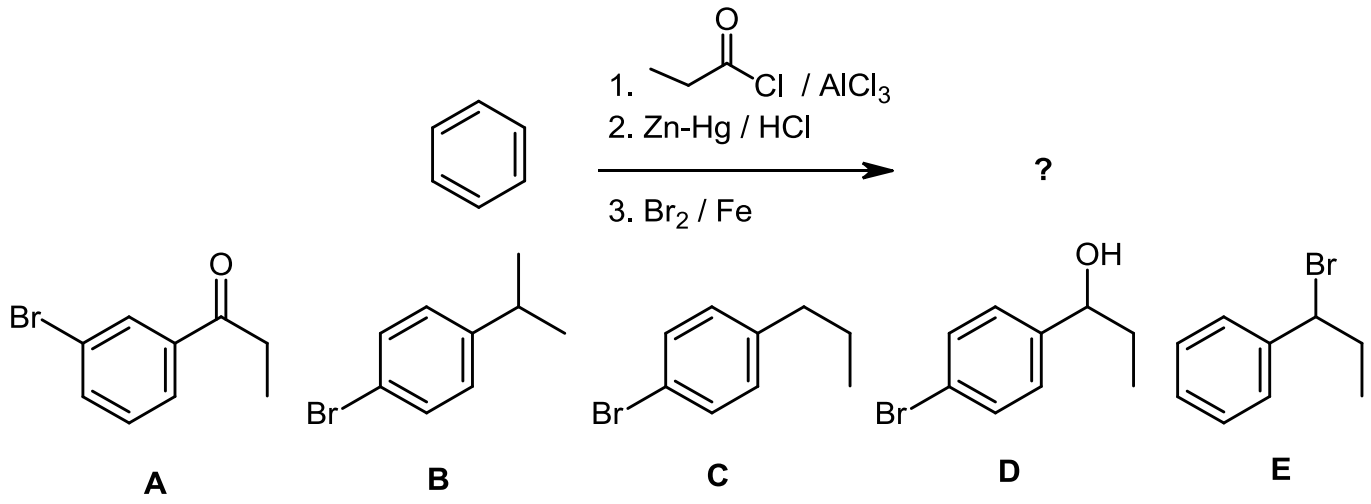
32.

? → 1. aq. H_2SO_4, $HgSO_4$; 2. CH_3CH_2MgBr then H_3O^+ → OH

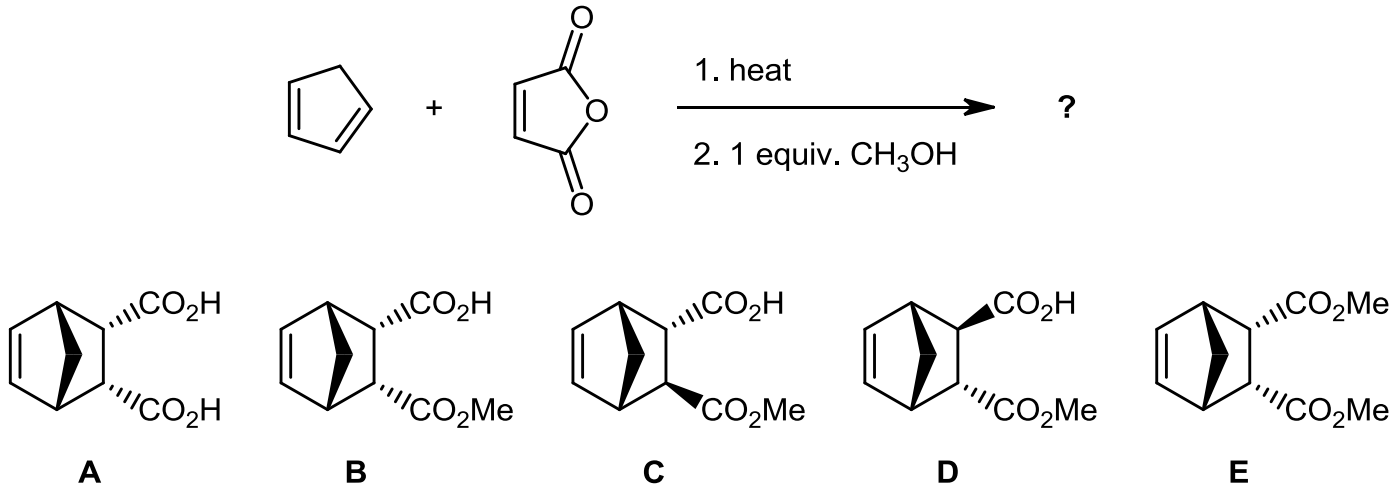


A **B** **C** **D** **E**

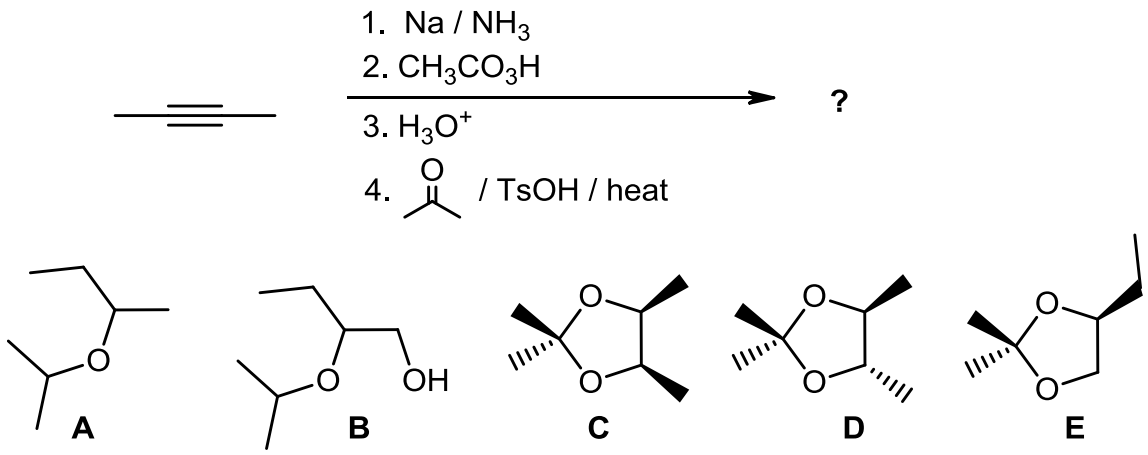
33.



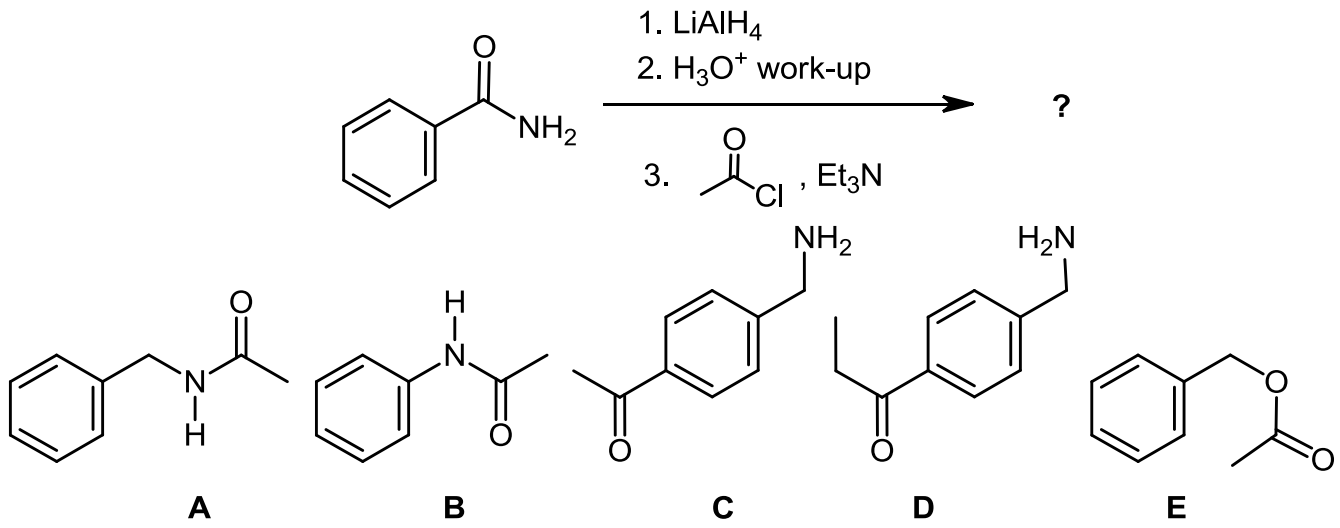
34.



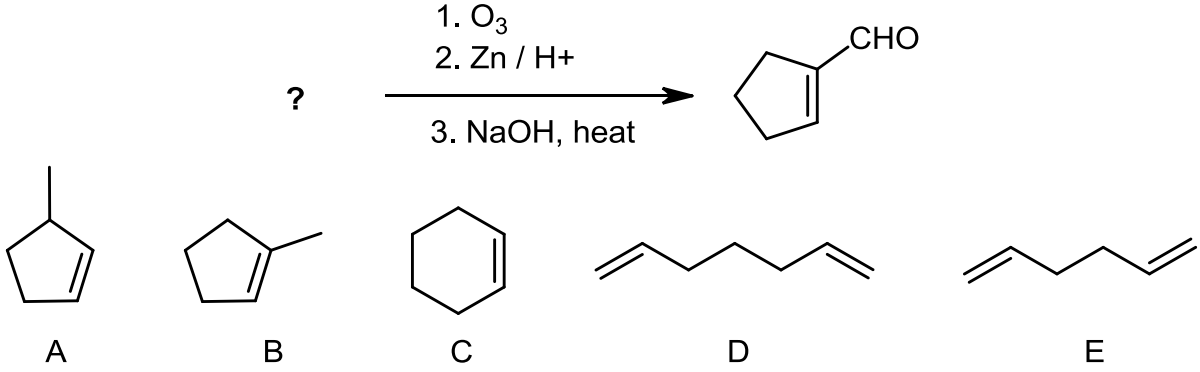
35.



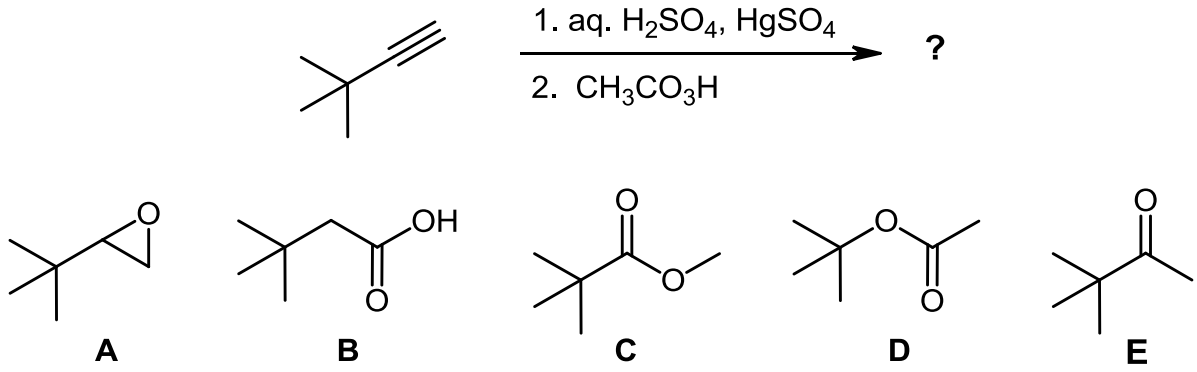
36.



37.



38.

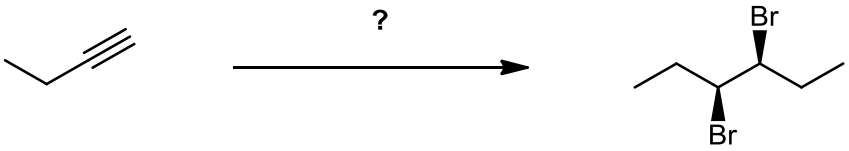


10% PART 5: REAGENTS FOR SYNTHESIS

ANSWER ANY FIVE (5) OF THE SIX (6) QUESTIONS 39-44

For each of the questions 39-44 identify the reagent(s) required in order to BEST complete each of the reaction sequences shown by selecting from the list provided.

39.



A. i. Br_2, ii. $NaNH_2$, CH_3CH_2Br, iii. H_2, Pd/C

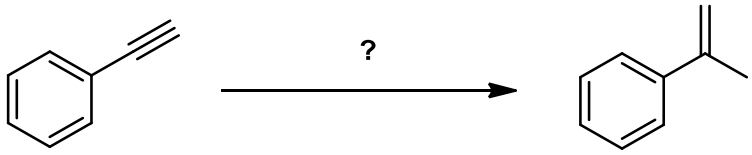
B. i. $NaNH_2$, CH_3CH_2Br, ii. H_2, Lindlar cat., iii. Br_2

C. i. H_2, Lindlar cat., ii. $NaNH_2$, CH_3CH_2Br, iii. Br_2

D. i. $NaNH_2$, CH_3CH_2Br, ii. Na, NH_3 iii. Br_2

E. i. Na, NH_3, ii. $NaNH_2$, CH_3CH_2Br, iii. Br_2

40.



A. i. $Hg(OAc)_2$, H_3O^+, ii. $(Ph)_3\overset{\oplus}{P}CH_3$, NaH

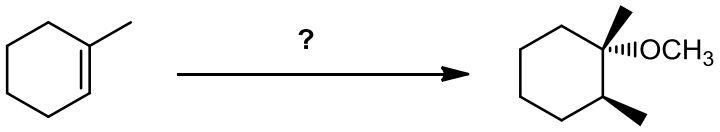
B. i. 9-BBN, ii. H_2O_2, aq. NaOH, iii. $(Ph)_3\overset{\oplus}{P}CH_3$, NaH

C. i. $Hg(OAc)_2$, H_3O^+, ii. $NaBH_4$, iii. PCl_3, Et_3N, iv. NaO*t*Bu

D. i. 9-BBN, ii. H_2O_2, aq. NaOH, iii. PCl_3, Et_3N, iv. NaO*t*Bu

E. i. MeMgBr, ii. H_2O, H_3O^+

41.



A. i. MeOH, ii. Me**I**, NaH

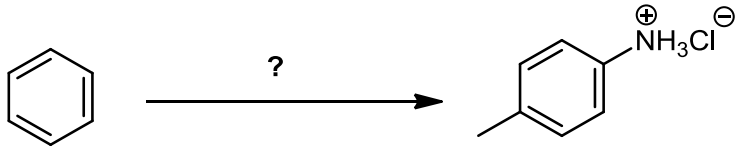
B. i. Me**I**, H_2SO_4, ii. peracetic acid, iii. $LiAlH_4$ then H_3O^+

C. i. MeMgBr then H_3O^+, ii. MeOH, H_2SO_4

D. i. peracetic acid, ii. MeOH, H_2SO_4

E. i. mCPBA, ii. MeMgBr then H_3O^+, iii. Me**I**, NaH

42.



A. i. H_2SO_4, HNO_3, ii. MeCl, $AlCl_3$, iii. Sn, HCl

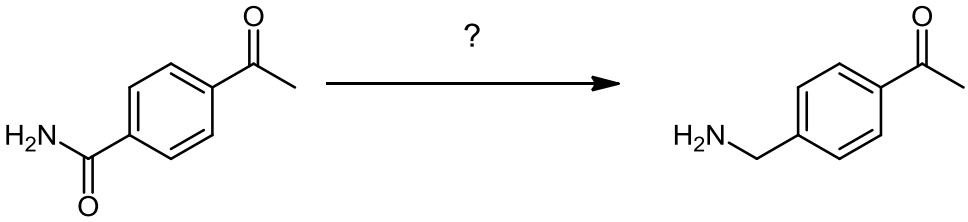
B. i NH_3, $AlCl_3$ ii. MeCl, $AlCl_3$

C. i. H_2SO_4, HNO_3, ii. Sn, HCl iii. MeCl, $AlCl_3$

D. i. MeCl, $AlCl_3$, ii. H_2SO_4, HNO_3, iii. Sn, HCl

E. i. MeCl, $AlCl_3$, ii. NH_3, $AlCl_3$

43.



A. H_2NNH_2, NaOH, heat

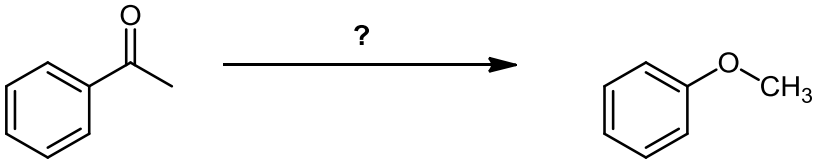
B. i. $LiAlH_4$, THF then H_3O^+, ii. H_3O^+, heat

C. i. $NaBH_4$, ii. PDC, iii. H_3O^+

D. i. $HOCH_2CH_2OH$, TsOH, ii. $LiAlH_4$, THF then H_3O^+ iii. H_3O^+, heat

E. i. Zn/Hg, HCl, ii. $NaBH_4$, EtOH

44.



A. i. $NaBH_4$, ii. H_3O^+, iii. H_2SO_4, MeOH

B. i. MeOH, heat, ii. H_3O^+

C. i. mCPBA, ii. NaOMe, MeOH, heat iii. LDA, MeI

D. i. $NaBH_4$, ii. H_3O^+, iii. mCPBA

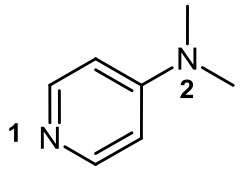
E. i. $NaBH_4$, ii. LDA, MeI, iii. mCPBA

10% PART 6: EXPLANATION OF PHENOMENA

ANSWER ALL FIVE (5) OF THE QUESTIONS 45 - 49.

Choose the single explanation that best rationalises the phenomenon indicated.

45. Dimethylaminopyridine has two basic nitrogen atoms labeled as **1** and **2** (shown below). Which N atom is more basic and why ?



A. N1 because the N1 lone pair is in an sp^2 hybrid orbital

B. N1 because the N1 lone pair is in a p orbital

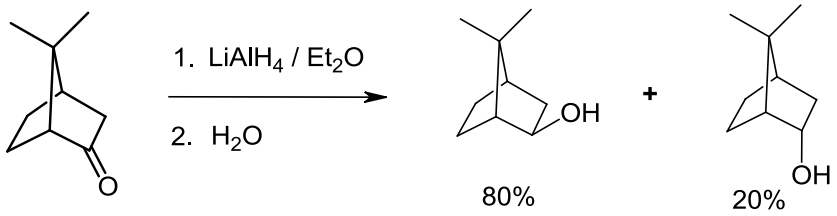
C. N1 because its conjugate acid is resonance stabilised

D. N2 because the N2 lone pair is in an sp^3 hybrid orbital

E. N2 because its conjugate acid is resonance stabilised

AB. N2 because the N2 lone pair is in an sp^2 hybrid orbital

46. The following ketone reacts with $LiAlH_4$ with the stereoselectivity shown below. This is because:



A. Substituents tend to prefer equatorial positions on cyclohexane ring systems

B. Polar substituents tend to prefer axial positions on cyclohexane ring systems

C. There is less steric hindrance if the nucleophile attacks from the top face

D. There is less steric hindrance if the nucleophile attacks from the bottom face

E. There is less steric hindrance if the electrophile attacks from the top face

AB. There is less steric hindrance if the electrophile attacks from the bottom face

47. Consider the reaction of bromobenzene with HNO_3 / H_2SO_4. Which isomer of bromonitrobenzene is the major product and why ?

A. ortho because the $–NO_2$ group is activating and o,p-directing

B. meta because the $–NO_2$ group is deactivating and m-directing

C. para due to steric effects and because the $–NO_2$ is activating and o,p-directing

D. ortho because the –Br group is activating and o,p-directing

E. meta because the –Br group is deactivating and m-directing

AB. para due to steric effects and because the –Br is deactivating and o,p-directing

48. Two carboxylic acid derivatives (an amide and an ester) are shown below. Which is more acidic and why ?

A. The ester because the conjugate base is better stabilized by resonance

B. The ester due to the electron donating effect of the methoxy group

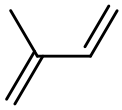
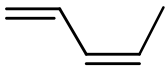
C. The ester due to the electronegativity of the O atom

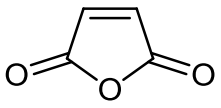
D. The amide due to the electronegativity of the N atom

E. The amide due to the electron donating effect of the amino group

AB. The amide because the conjugate base is better stabilized by resonance

49. Which of the following reacts faster with maleic anhydride and why ?

X   **Y**



maleic anhydride

A. X because it has an electron donating substituent that activates it

B. X because it has an electron withdrawing substituent that activates it

C. X because the reactive conformation of **Y** is destabilised

D. Y because it has an electron donating substituent that activates it

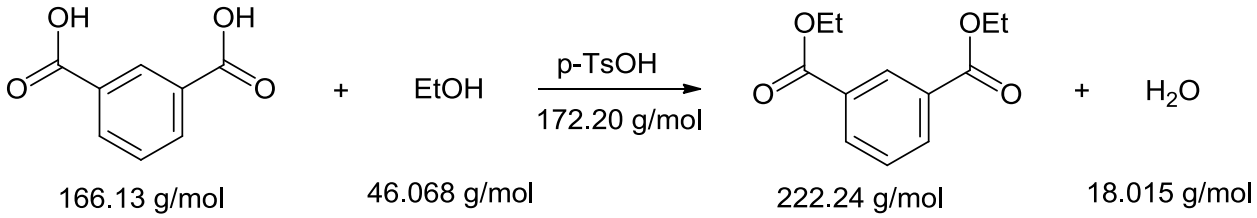
E. Y because it has an electron withdrawing substituent that activates it

AB. Y because the reactive conformation of **X** is destabilised

5% PART 7: LABORATORY

WRITE YOUR ANSWERS IN THE BLUE ANSWER BOOKLET PROVIDED.

Calculate the % yield of the ester product (show your working) based on the following experimental data.



166.13 g/mol 46.068 g/mol 172.20 g/mol 222.24 g/mol 18.015 g/mol

Densities: ethanol = 0.79 g/mL, chloroform = 1.56 g/mL, ethyl ethanoate = 0.90 g/mL

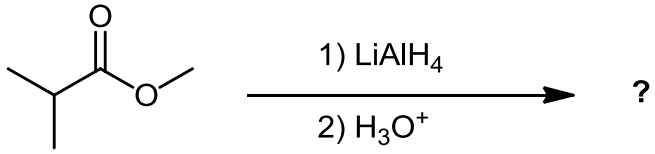
m-Phthalic acid (1.66 g) and anhydrous ethanol (1.50 mL) were mixed in anhydrous chloroform (5.0 mL), and a few crystals of p-tosic acid were added. After heating the solution for 3 hours at 50 °C, the reaction mixture was cooled and evaporated to dryness. The crude solid mixture was dissolved in ethyl ethanoate (15 mL), and the solution was washed with 10% $NaHCO_3$ (15 mL), 2M HCl (15 mL), and then dried over anhydrous Na_2SO_4. After filtration, the organic solution was evaporated on a rotary evaporator and dried under high vacuum to afford diethyl phthalate as a colorless oil (1.111 g).

8% **PART 8: MECHANISM**

ANSWER TWO (2) QUESTIONS, ONE FROM PART A AND ONE FROM PART B.
WRITE YOUR ANSWERS IN THE BLUE ANSWER BOOKLET PROVIDED.
NO REAGENTS OTHER THAN THOSE ALREADY SHOWN IN EACH QUESTION ARE REQUIRED.

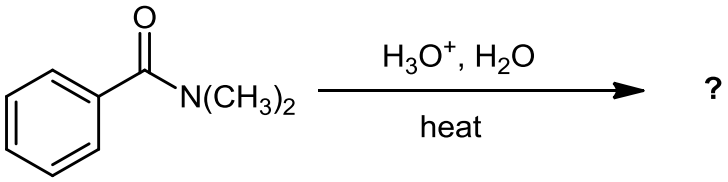
(4) PART A: Draw the curly arrow mechanism for ONE of the following transformations:

i.



OR

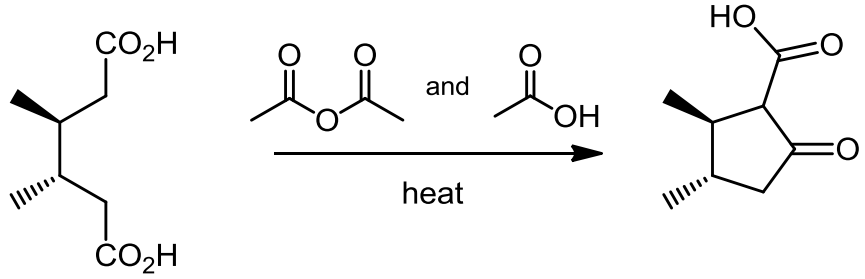
ii.



(4) PART B : Draw the curly arrow mechanism for ONE of the following transformations:

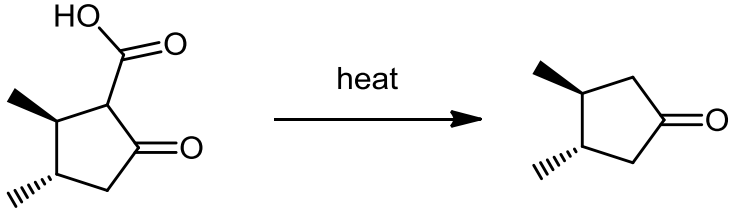
The Blanc cyclization is a method to rapidly prepare cyclic ketones from di-acids applying chemistry we have learned in Chem 353.

i. Provide a mechanism for the first part of the Blanc reaction shown below:



OR

ii. Provide a mechanism for the second part of the Blanc reaction shown below:

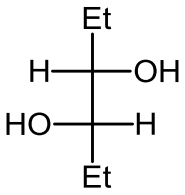


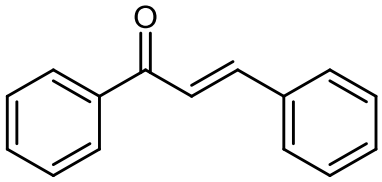
12% PART 9: TOTAL SYNTHESIS

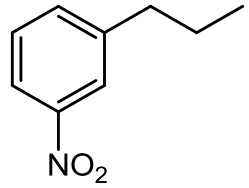
WRITE YOUR ANSWERS IN THE BLUE ANSWER BOOKLET PROVIDED.

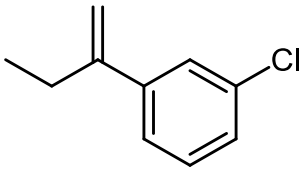
Design an efficient synthesis from the starting materials in the list below for THREE (3) of the following target molecules. Choose ONE target from each of the three sections A, B and C. DO NOT SHOW MECHANISMS (*i.e.* curly arrows are NOT required)

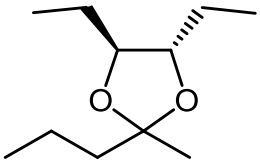
SHOW YOUR ANSWER AS A STEPWISE REACTION SCHEME SHOWING THE REAGENT REQUIRED FOR EACH STEP AND THE SYNTHETIC INTERMEDIATE FORMED FROM EACH REACTION.

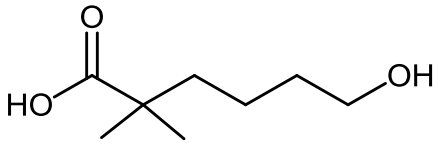
A 

or 

B 

or 

C 

or 

Permitted Materials and Reagents

NOTE: any materials that contribute carbon atoms to the target molecule must come from this allowed list:

- any organic compounds with no more than **FOUR** carbons
- benzene
- cyclohexanol
- You can use any solvents or other reagents for the reactions provided that they do not contribute carbon atoms to the target.

10% PART 10: STRUCTURE DETERMINATION

WRITE YOUR ANSWERS IN THE BLUE ANSWER BOOKLET PROVIDED

Compound **A** ($C_{12}H_{22}O$) is an achiral compound and a constituent of the sex pheromone of the common cutworm. After refluxing **A** in aq. NaOH and dilute aq. acid work up, two new compounds were obtained, ethanoic acid and **B**, $C_{10}H_{20}O$.

Compound **B** was then treated with pyridinium chlorochromate (PCC) in methylene chloride to give **C**. **C** gave a yellow precipitate when tested with 2,4-dinitrophenylhydrazine and a deposit of silver in the Tollen's test. **C** was then reduced with NH_2NH_2 / ethylene glycol / heat to give **D**, $C_{10}H_{20}$. Reaction of **D** with $KMnO_4$ / aq. NaOH at 0^oC gave **E**, a meso diol, $C_{10}H_{22}O_2$.

Alternatively, **B** was reacted with ozone followed by work-up with H_2O_2 to give two new compounds **F**, $C_5H_{10}O_2$ and **G**, $C_5H_{10}O_3$. Compound **G** was observed to readily lose water to give **H**, $C_5H_8O_2$ which was found to be identical to the compound formed when cyclopentanone was reacted with CH_3CO_3H. The identity of compound **F** was confirmed by independent synthesis: diethyl malonate (also known as diethyl propanedioate) was reacted with sodium ethoxide in ethanol and then 1-bromopropane with added catalytic NaI. Hydrolysis of the resulting product by heating with aq. NaOH and then acidification / heat resulted in the evolution of a gas and the formation of **F**.

Identify the compounds A to H showing any relevant stereochemistry (drawn structures are sufficient).

THE END

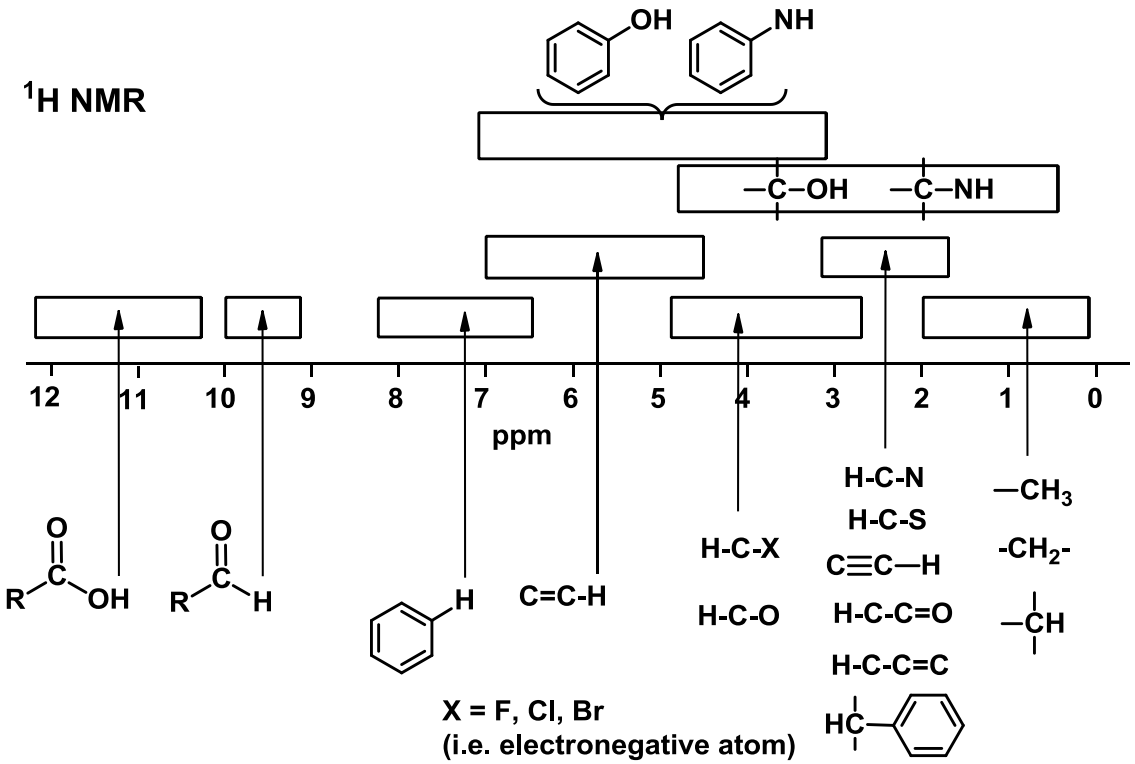
IRH / DD W2019

PERIODIC TABLE

1 1A																	18 8A
1 **H** 1.008	**2** 2A											**13** 3A	**14** 4A	**15** 5A	**16** 6A	**17** 7A	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57* **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.0	89** **Ac** (227)	104 **Rf** (261)	105 **Ha** (262)	106 **Sg** (263)	107 **Ns** (262)	108 **Hs** (265)	109 **Mt** (266)	110 **Uun** (269)	111 **Uuu** (272)							

Lanthanides *	58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
Actinides **	90 **Th** 232.0	91 **Pa** 231.0	92 **U** 238.0	93 **Np** 237.0	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (260)

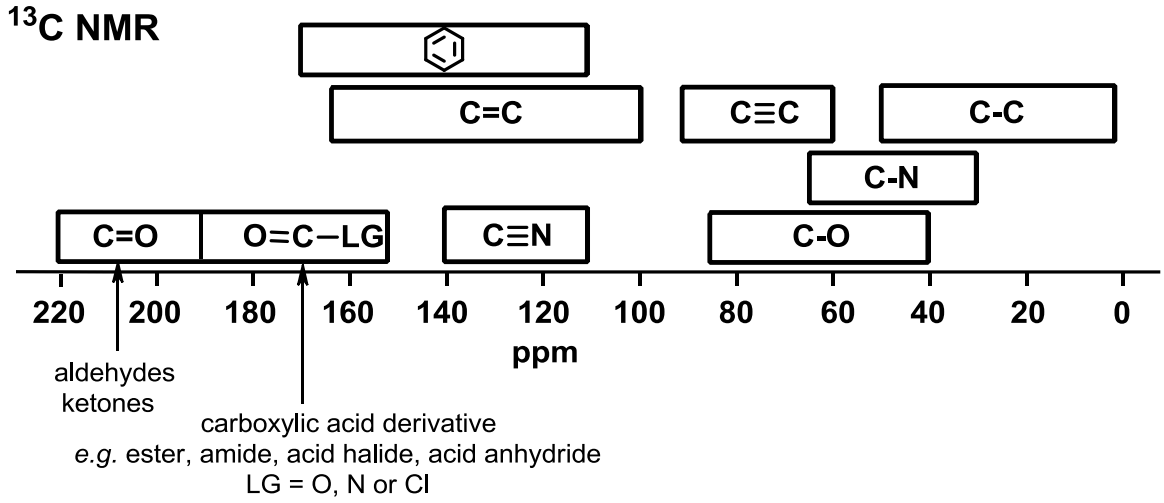
SPECTROSCOPIC TABLES



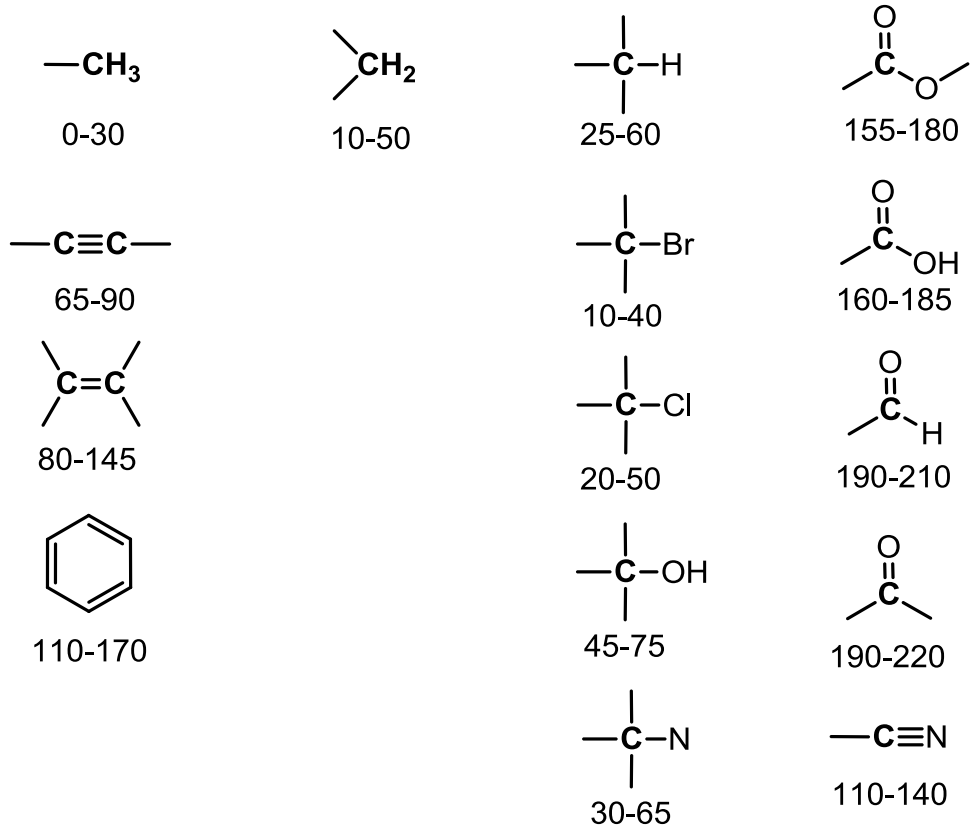
^{1}H NMR CHARACTERISTIC CHEMICAL SHIFTS / ppm

R =	methyl —CH_3	methylene -CH_2-	methyne —CH
R—C—	0.9	1.4	1.5
R, C=C	1.6	2.3	2.6
R—C(=O)—	2.1	2.4	2.5
R—N	2.2	2.5	2.9
R—Ar	2.3	2.7	3.0
R—Br	2.7	3.3	4.1
R—Cl	3.1	3.4	4.1
R—O—	3.3	3.4	3.7

other	
sp^3C-OH	1-5
sp^3C-NH	1-3
C≡CH	2.5
C=C(H)	4.5-6.5
H—Ar	6.5-8
R—C(=O)—H	9-10
R—C(=O)—OH	9-12



^{13}C NMR CHARACTERISTIC CHEMICAL SHIFTS / ppm



INFRA-RED GROUP ABSORPTION FREQUENCIES

		TYPE OF VIBRATION	FREQUENCY (cm^{-1})	WAVELENGTH (μ)	INTENSITY (1)
C–H	Alkanes	(stretch)	3000-2850	3.33-3.51	s
	$-CH_3$	(bend)	1450 and 1375	6.90 and 7.27	m
	$-CH_2-$	(bend)	1465	6.83	m
	Alkenes	(stretch)	3100-3000	3.23-3.33	m
		(bend)	1700-1000	5.88-10.0	s
	Aromatics	(stretch)	3150-3050	3.17-3.28	s
		(out-of-plane bend)	1000-700	10.0-14.3	s
	Alkyne	(stretch)	ca. 3300	ca.3.03	s
	Aldehyde		2900-2800	3.45-3.57	w
			2800-2700	3.57-3.70	w
C–C	Alkane	not usually useful			
C=C	Alkene		1680-1600	5.95-6.25	m-w
	Aromatic		1600-1400	6.25-7.14	m-w
C≡C	Alkyne		2250-2100	4.44-4.76	m-w
C=O	Aldehyde		1740-1720	5.75-5.81	s
	Ketone		1725-1705	5.80-5.87	s
	Carboxylic acid		1725-1700	5.80-5.88	s
	Ester		1750-1730	5.71-5.78	s
	Amide		1700-1640	5.88-6.10	s
	Anhydride		ca. 1810	ca. 5.52	s
			ca. 1760	ca. 5.68	s
	Acyl chloride		1800	5.55	s
C–O	Alcohols, Ethers, Esters,				
	Carboxylic acids		1300-1000	7.69-10.0	s
O–H	Alcohols, Phenols				
	Free		3650-3600	2.74-2.78	m
	H-Bonded		3400-3200	2.94-3.12	m
	Carboxylic acids (2)		3300-2500	3.03-4.00	m
N–H	Primary and secondary amines		ca. 3500	ca. 2.86	m
C≡N	Nitriles		2260-2240	4.42-4.46	m
N=O	Nitro ($R-NO_2$)		1600-1500	6.25-6.67	s
			1400-1300	7.14-7.69	s
C–X	Fluoride		1400-1000	7.14-10.0	s
	Chloride		800-600	12.5-16.7	s
	Bromide, Iodide		<600	>16.7	s

(1) s = strong, m = medium and w = weak

(2) note that the -OH absorption of solid carboxylic acids run as a nujol mull can be difficult to see as they may be very broad.