UNIVERSITY OF CALGARY

FACULTY OF SCIENCE

MIDTERM EXAMINATION

CHEMISTRY 353

Version 1

WEDNESDAY MARCH 9th, 2016 Time: 2 Hours

READ ALL THE INSTRUCTIONS CAREFULLY

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

The exam consists of **Parts 1 - 7**, each of which should be attempted. Note that some Parts provide you with a choice of questions, *e.g*. answer any 5 out of 6. These will be graded in numerical order until the required number have been completed, regardless of whether they are right or wrong. **Parts 1 - 4** will be computer graded, and **Parts 5, 6 and 7** are to be answered **IN THE BOOKLET PROVIDED**. A periodic table with atomic numbers and atomic weights and spectroscopic data tables are included with this examination paper.

Parts 1 - 4 consist of a series of multiple choice questions numbered 1 - 34 which are to be answered on the computer answer sheet. Indicate your answer by blackening out the appropriate space, A, B, C, D or E on the answer sheet. Use a soft 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***.
Molecular models are permitted during the exam; calculators are also permitted, ***but NOT programmable calculators***. **Absolutely no other electronic devices are allowed.**

16% **PART 1: RELATIVE PROPERTIES**

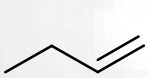
ANSWER ANY EIGHT (8) OF QUESTIONS 1-10.

Arrange the items in each of the questions in this section in DECREASING ORDER (*i.e.* greatest first) with respect to the indicated property.

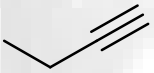
Use the following code to indicate your answers.

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

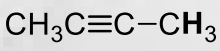
1. The relative reactivity of each of the following towards HCl:

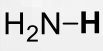

i

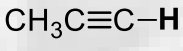

ii


iii

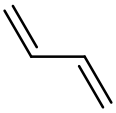
2. The relative acidity of the **H** atom in each of the following:


i

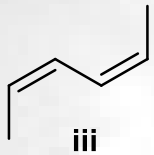

ii

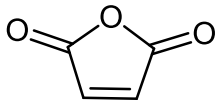

iii

3. The relative reactivity towards maleic anhydride (shown below) of each of the following:

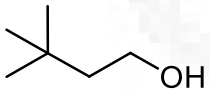

i

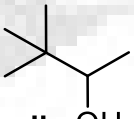

ii

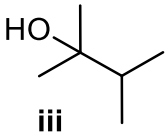

iii


maleic anhydride

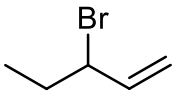
4. The relative yields of the following products from the reaction of 3,3-dimethylbut-1-ene with (i) $HgSO_4$ / aq. H_2SO_4 then (ii) $NaBH_4$:

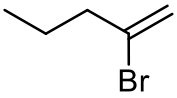

i

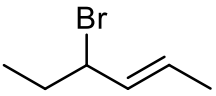

ii


iii

5. The number of configurational isomers of each of the following:


i

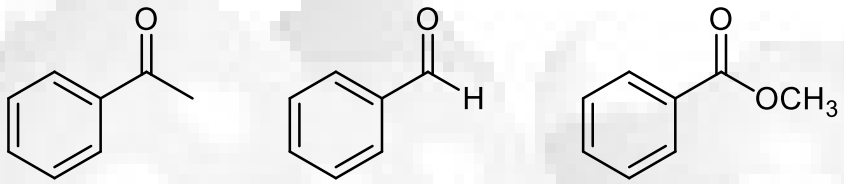

ii


iii

Use the following code to indicate your answers.

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 relative reactivity towards sodium borohydride of each of the following:

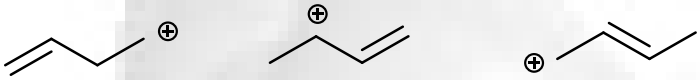


i **ii** **iii**

7. The relative reactivity of each of the following towards aq. H_2 / Pd :

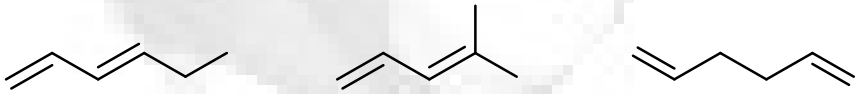
i **ii** **iii**

8. The relative stability of the following carbocations as drawn:



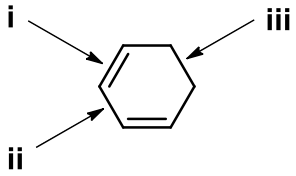
i **ii** **iii**

9. The relative number of allylic hydrogens in each of the following isomers:



i **ii** **iii**

10. The relative length of the indicated **CC** bonds:

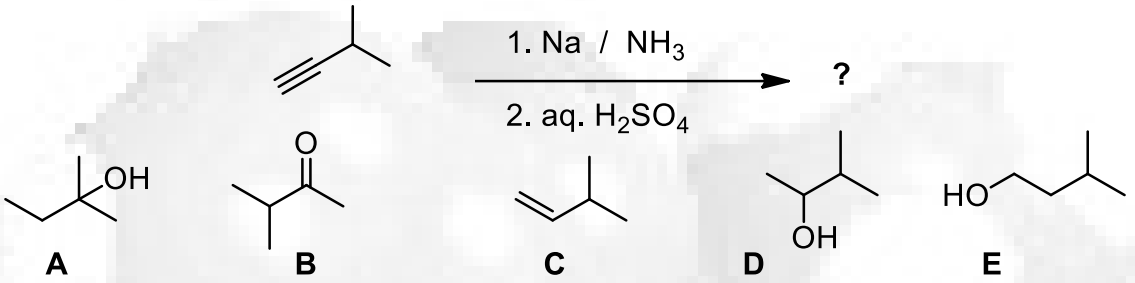


14% PART 2: STARTING MATERIALS, REAGENTS AND PRODUCTS

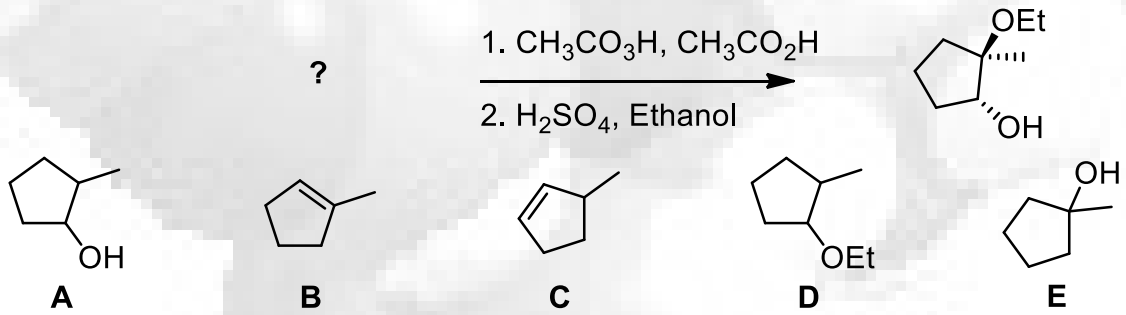
ANSWER ANY SEVEN (7) OF QUESTIONS 11-18.

For each of questions 11-18 select the MISSING component (the starting material, the product or the reagents) required in order to BEST complete each of the reaction schemes.

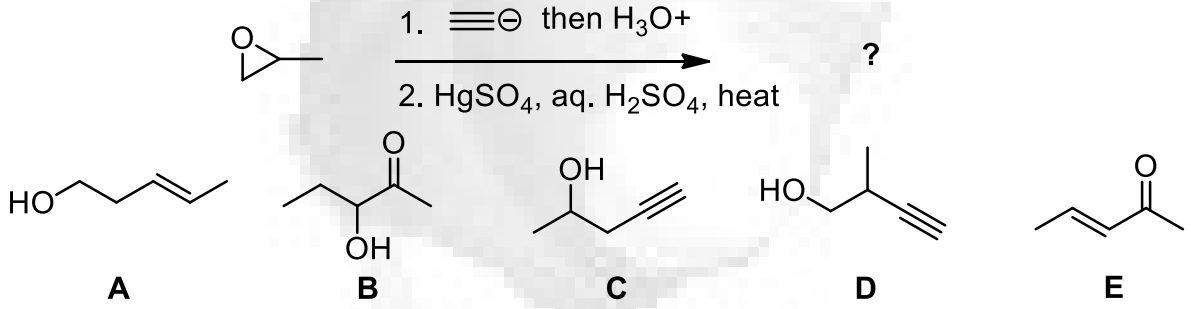
11.



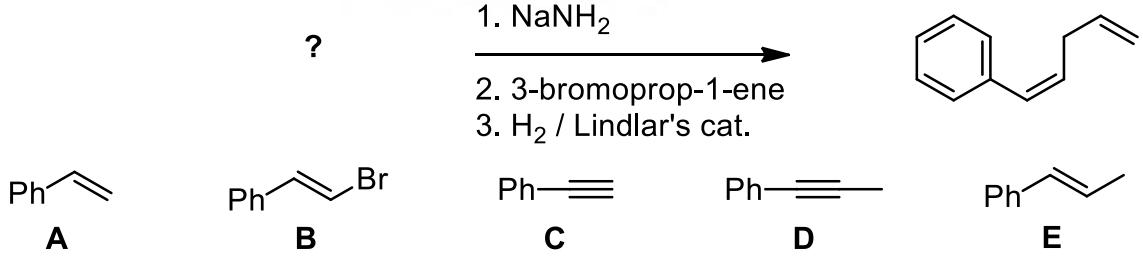
12.



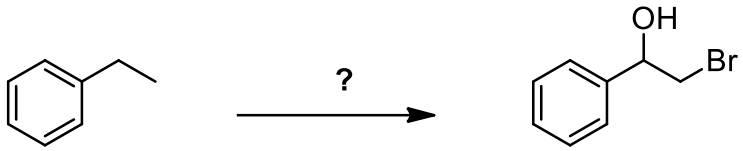
13.



14.



15.



A 1. Br_2; 2. NaOMe, MeOH, heat; 3. aq. H_2SO_4, heat

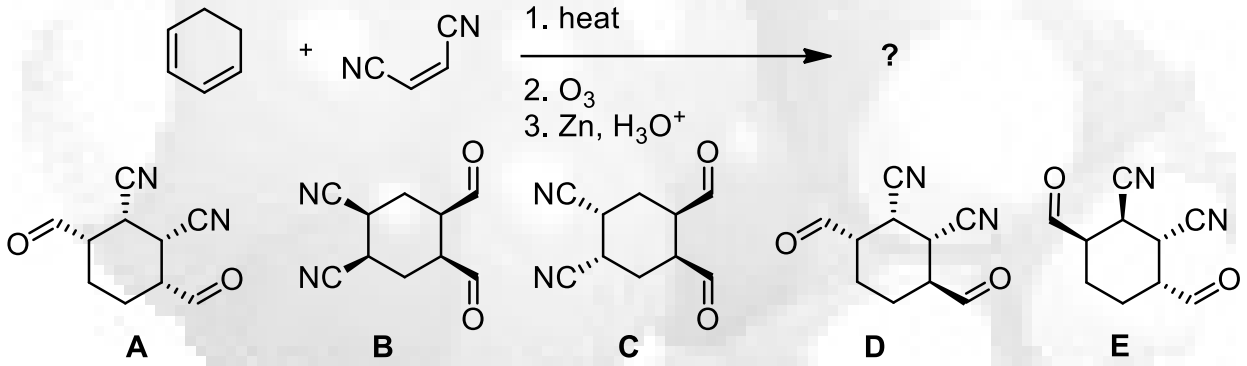
B 1. HBr, dark; 2. Sodium tert-butoxide, heat; 3. CH_3CO_3H

C 1. NBS, heat; 2. NaOMe, MeOH, heat; 3. HOBr

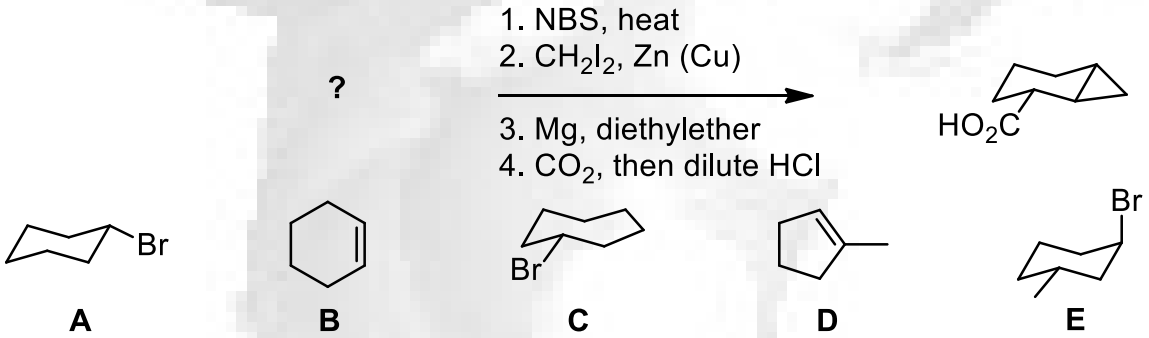
D 1. HBr, dark; 2. 1-butyne, $NaNH_2$; 3. Na, NH_3

E 1. NBS, heat; 2. CH_3CO_3H; 3. aq. HBr

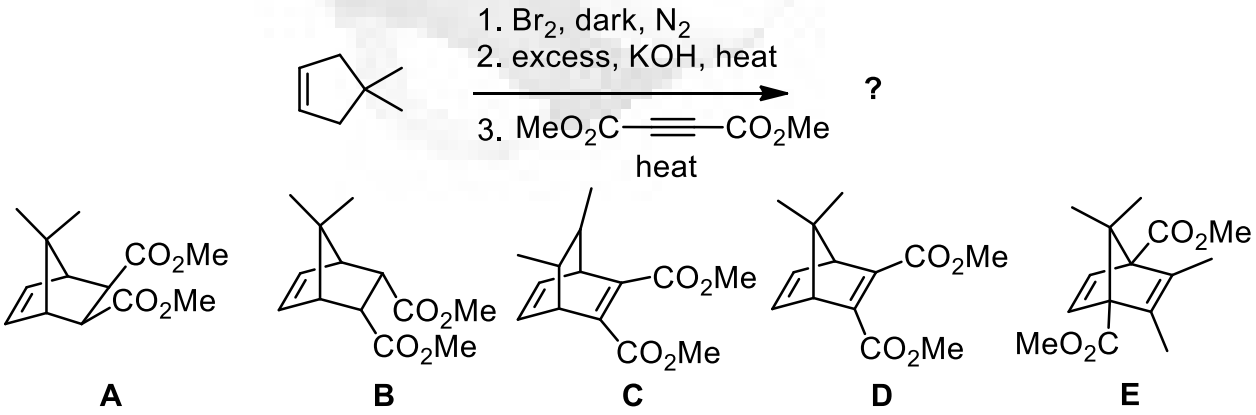
16.



17.



18.

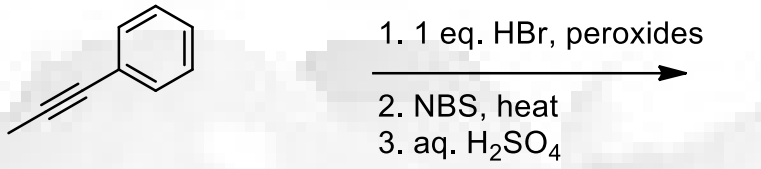


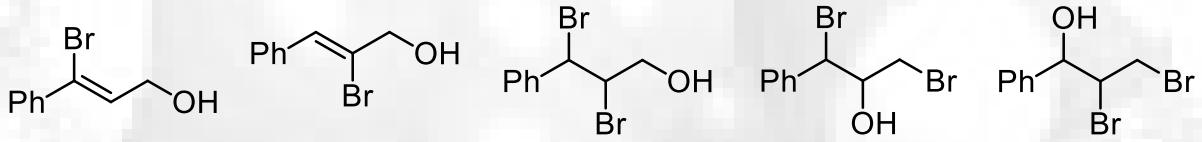
PART 3: REGIOCHEMISTRY and STEREOCHEMISTRY OF REACTIONS

18% **ANSWER ANY SIX (6) OF QUESTIONS 19-25**.

For each of the questions 19-25, select the structure required to BEST complete the reaction shown.

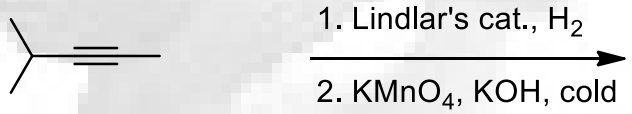
19.

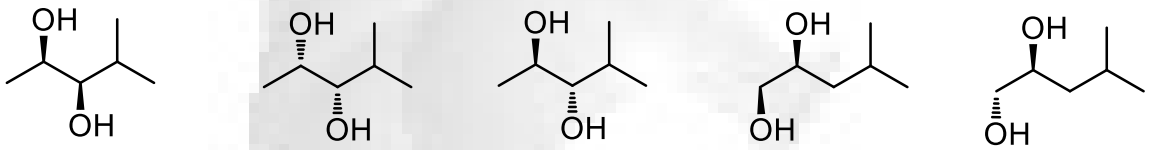




A **B** **C** **D** **E**

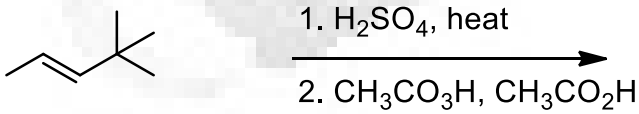
20.

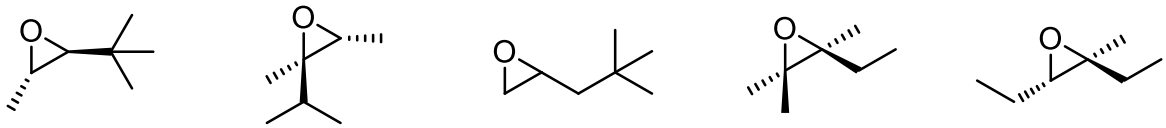




A **B** **C** **D** **E**

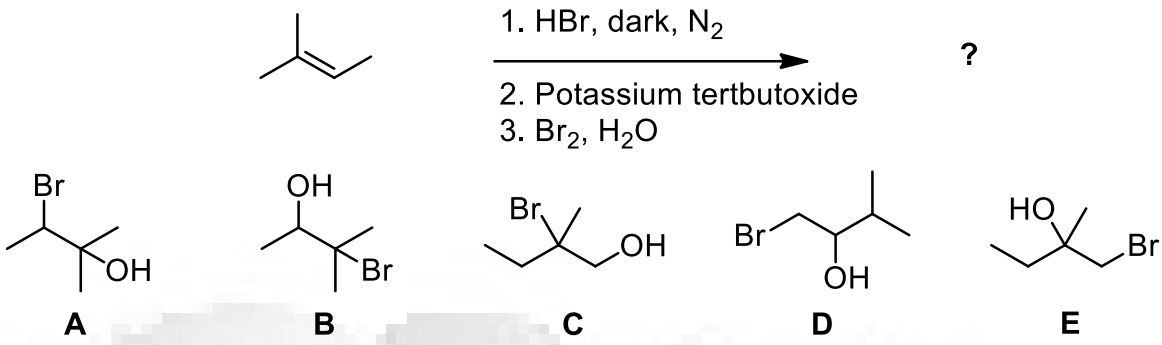
21.



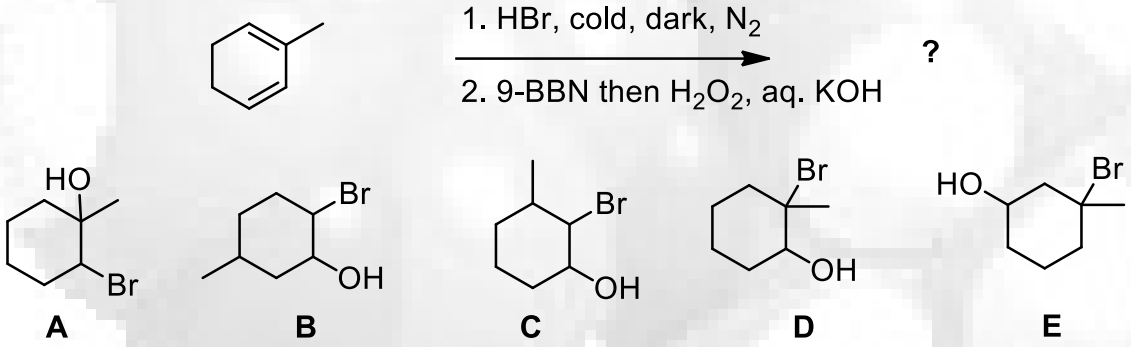


A **B** **C** **D** **E**

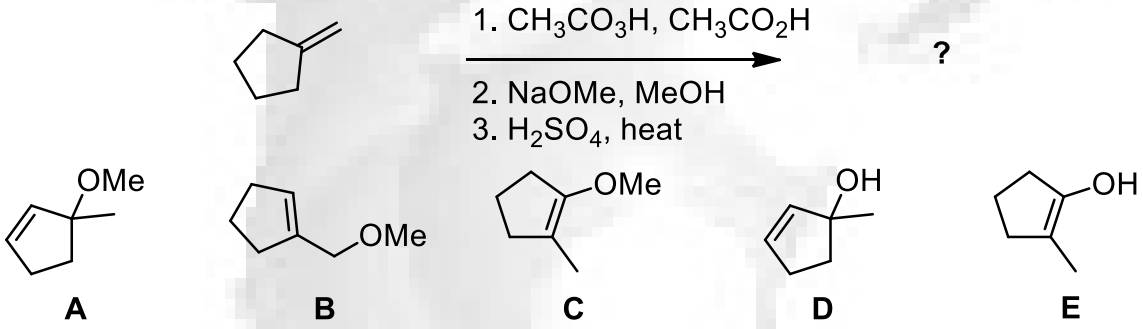
22.


1. HBr, dark, N2
2. Potassium tertbutoxide
3. Br2, H2O
?
A
B
C
D
E

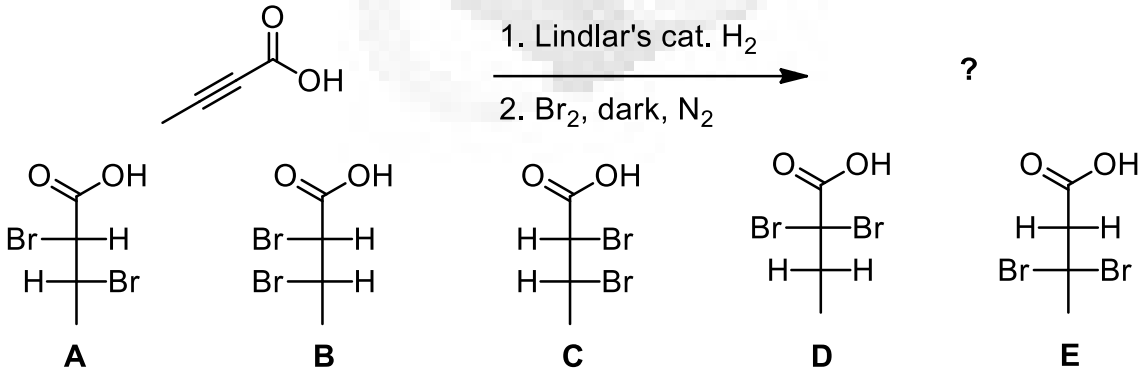
23.


1. HBr, cold, dark, N2
2. 9-BBN then H2O2, aq. KOH
?
A
B
C
D
E

24.


1. CH3CO3H, CH3CO2H
2. NaOMe, MeOH
3. H2SO4, heat
?
A
B
C
D
E

25.

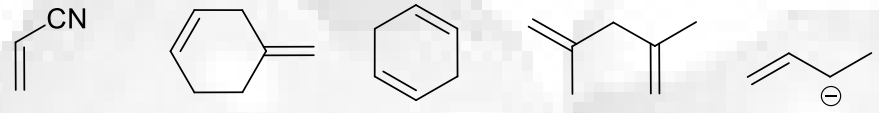

1. Lindlar's cat. H2
2. Br2, dark, N2
?
A
B
C
D
E

16% PART 4: PI SYSTEMS

ANSWER ANY EIGHT (8) of the questions 26 - 34.

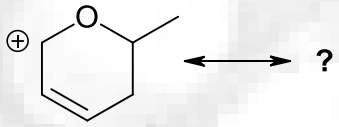
For each of the questions 26-34 select the appropriate answer from the answers provided. In some cases more than one selection may be required for full credit.

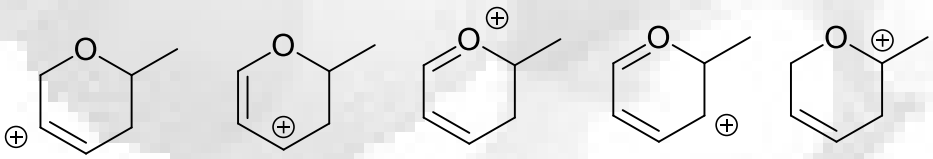
26. Which of the following contain conjugated systems? **(select all that apply)**



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

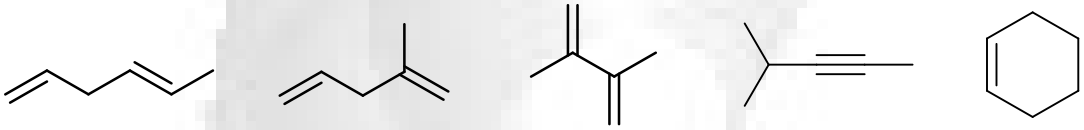
27. Which of the following systems are resonance contributors of the cation shown to the right ? **(select all that apply)**





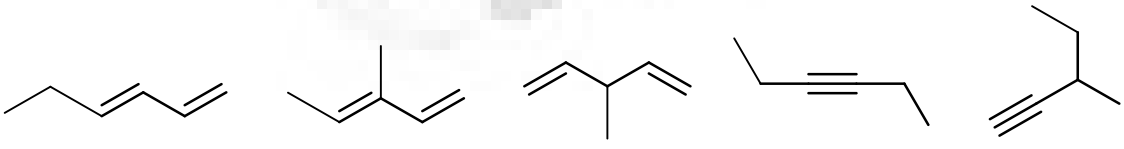
A **B** **C** **D** **E**

28. Which of the following isomers reacts **fastest** with aq. H_2SO_4 ?



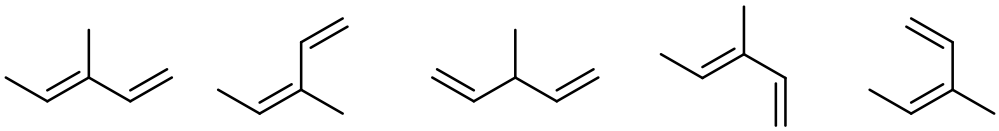
A **B** **C** **D** **E**

29. Which of the following isomers is the **most** stable ?



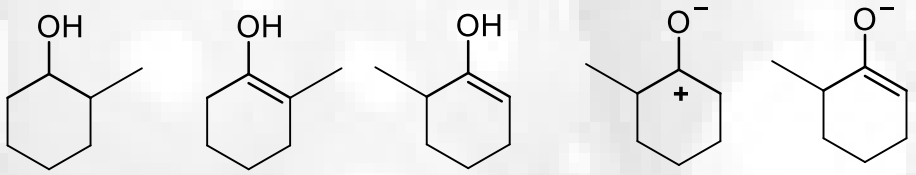
A **B** **C** **D** **E**

30. Which of the following molecules is the *s-cis* form of (3E)-3-methylpenta-1,3-diene?



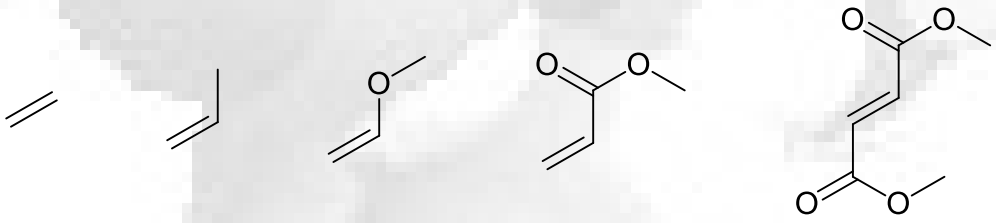
A **B** **C** **D** **E**

31. Which of the following systems are tautomers of 2-methylcyclohexanone? **(select all that apply)**



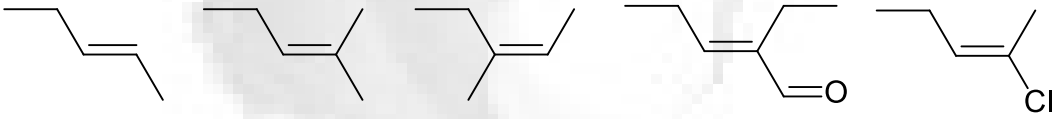
A **B** **C** **D** **E**

32. Which of the following systems would be the **most** reactive towards 1,3-cyclopentadiene ?



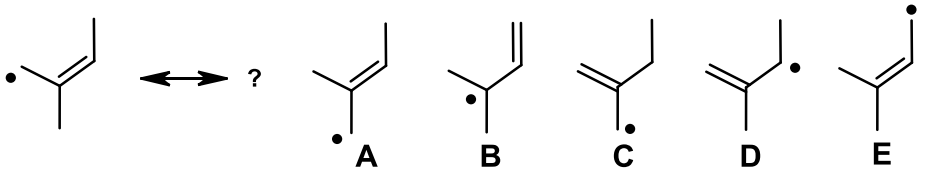
A **B** **C** **D** **E**

33. Which of the following molecules would be named as *cis* ? **(select all that apply)**



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

34. Which of the following systems are resonance contributors of the radical shown below ? **(select all that apply)**



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

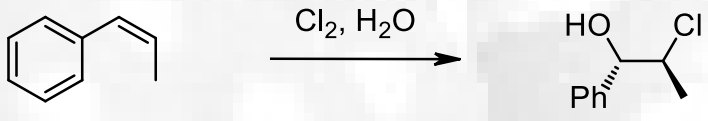
10% PART 5: MECHANISMS

ANSWER TWO (2) QUESTIONS, ONE FROM PART A and ONE FROM PART B

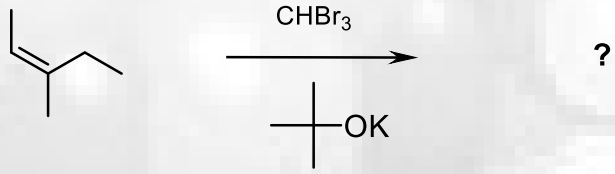
WRITE YOUR ANSWER IN THE BOOKLET PROVIDED

Draw curly arrow mechanisms to explain the following reactions / observations. No other reagents are required.

A. Show the mechanism for **one** of the following reactions:

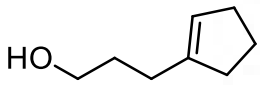


OR



AND

B. Predict the product and show the mechanism for **one** of the following reactions:

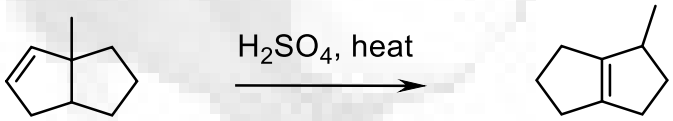


1. $Hg(OAc)_2$, THF
2. $NaBH_4$, KOH

?

Only show the mechanism for the reaction of the starting material with the reagents in **step 1**

OR



15% PART 6: SYNTHESIS

ANSWER THREE (3) QUESTIONS, ONE FROM A, ONE FROM B AND ONE FROM C.

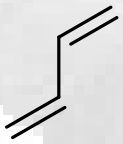
WRITE YOUR ANSWERS IN THE BOOKLET PROVIDED.

Design an efficient synthesis for any THREE (3) of the following target molecules

SHOW YOUR ANSWER AS A STEPWISE REACTION SCHEME SHOWING THE REAGENT REQUIRED AND PRODUCT OF EACH STEP

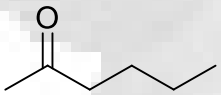
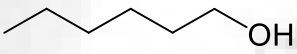
DO NOT SHOW MECHANISMS (*i.e.* curly arrows are NOT required)

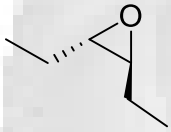
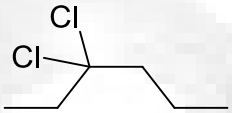
Allowed starting materials and reagents:

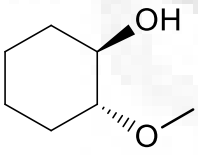
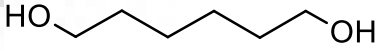


Any hydrocarbons with 3 or less C atoms

Any solvents or reagents that do not contribute carbon atoms to the final structure.

A  **or** 

B  **or** 

C  **or** 

11% PART 7: STRUCTURE DETERMINATION

WRITE YOUR ANSWER IN THE BOOKLET PROVIDED

Use the information in the following paragraph to answer the questions below.

Compound **A** (C_6H_{12}), was reacted with H_2 over Pd to give **B** (C_6H_{14}). When **A** was reacted with Cl_2, the major product **C** was obtained as a single configurational isomer.

Compound **D**, a isomer of **A**, also reacted with H_2 over Pd to give **B**. But when **D** was reacted with Cl_2, the major product **E** was obtained as a pair of enantiomers.

Compound **F**, also an isomer of **A**, did not react with H_2 over Pd and only reacted with Cl_2 in the presence of uv light to give **G**, as the only monochlorinated compound. **G** was found to be achiral.

Both **A** and **D** reacted with O_3 followed by work up with zinc in acid to give a single product, **H** (IR 1739 cm^{-1}, H-NMR/ppm 1.1 (3H, t), 2.5 (2H, q), 9.8 (1H, s). **F** did not react with with O_3.

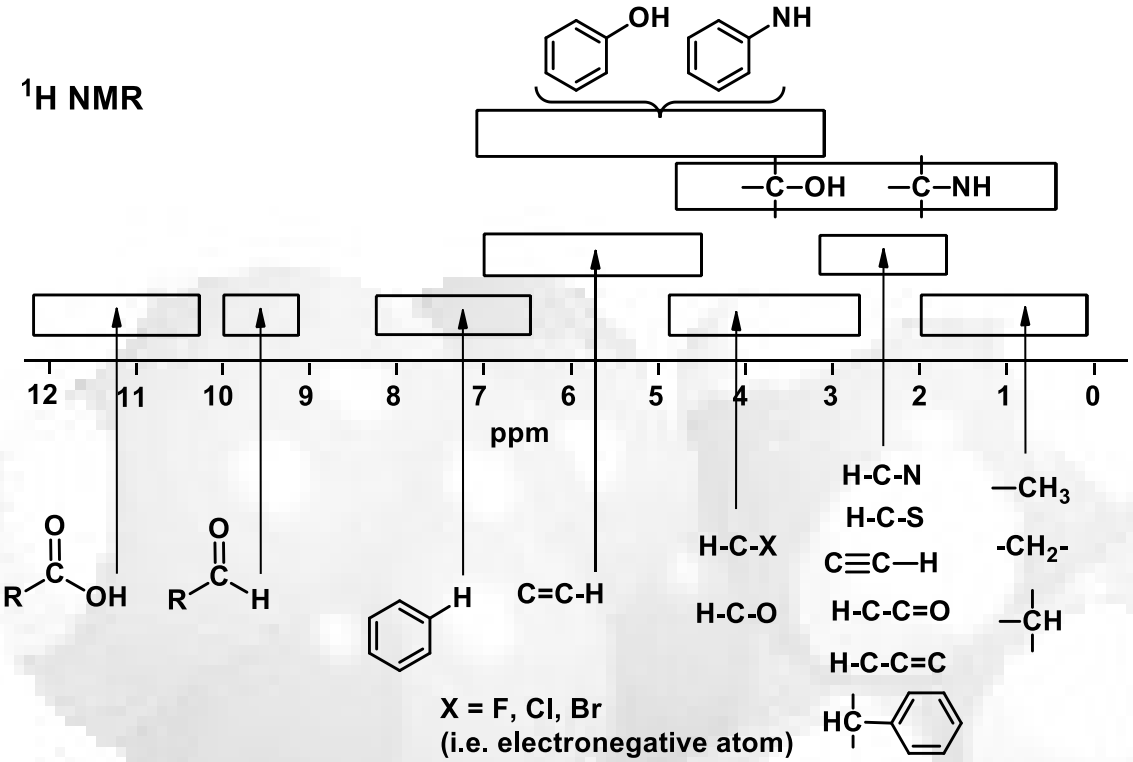
Draw the structures of A to H.

*** THE END ***

IRH / TCS / W16

SPECTROSCOPIC TABLES

^{1}H NMR

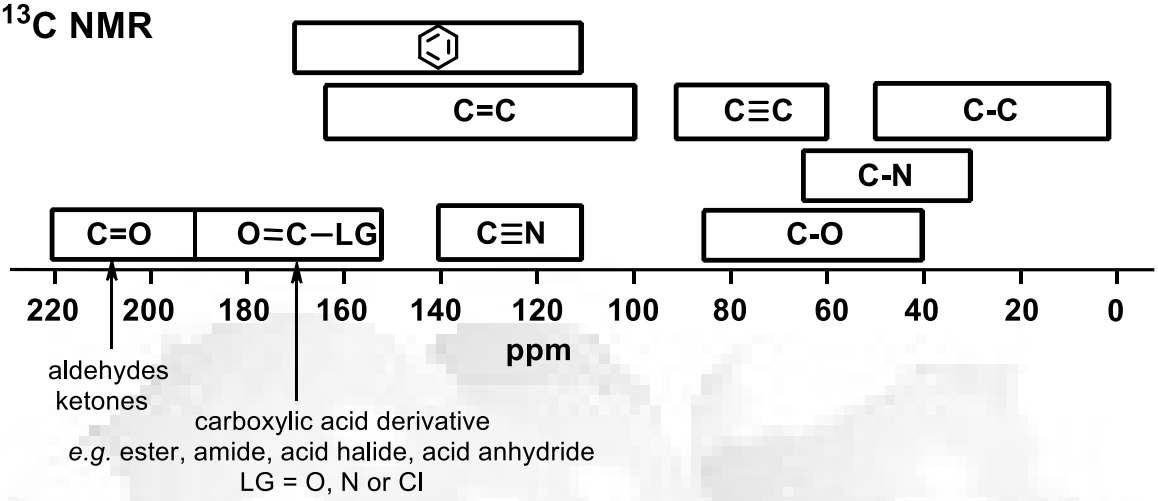


^{1}H NMR CHARACTERISTIC CHEMICAL SHIFTS / ppm

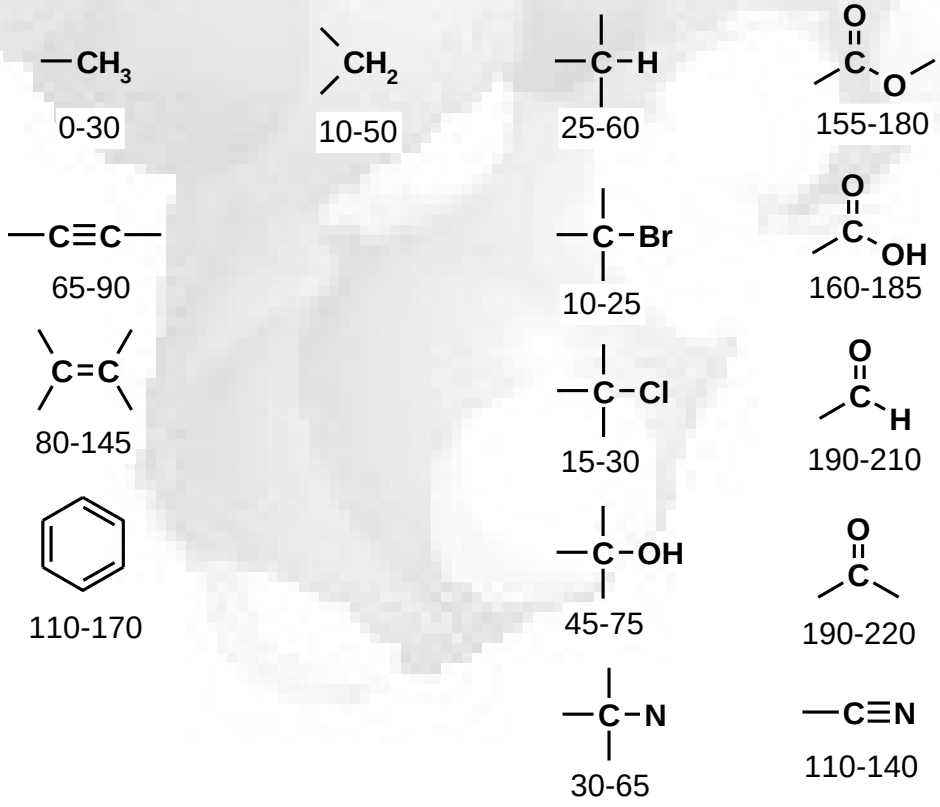
R =	methyl $-CH_3$	methylene $-CH_2-$	methyne $-CH$
R–C—	0.9	1.4	1.5
R, C=C	1.6	2.3	2.6
R–C(=O)—	2.1	2.4	2.5
R–N	2.2	2.5	2.9
R–Ar	2.3	2.7	3.0
R–Br	2.7	3.3	4.1
R–Cl	3.1	3.4	4.1
R–O—	3.3	3.4	3.7

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



^{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 which run as a nujol mull can be difficult to see as they maybe very broad.

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)