McMaster University
Inspiring Innovation and Discovery

Version 1

CHEM 2OA3 Summer 2013

Dr. P. Harrison & G. Bahun

Final Examination

June 20th, 2013, 6:00 – 9:00 PM

NAME_____

STUDENT NUMBER_____

DO NOT OPEN THIS EXAM UNTIL INSTRUCTED TO DO SO.

THIS TEST CONSISTS OF 26 PAGES. You are responsible for ensuring that your copy of the test paper is complete. Bring any discrepancy to the attention of the invigilator BEFORE you begin writing the test. You are permitted to use molecular models and the standard McMaster standard calculator (Casio FX 991**). NO OTHER AIDS ARE ALLOWED! Tables of spectral and other data are provided on pages 24 to 26.**

THIS TEST IS IN TWO PARTS. PART I IS WORTH 40% AND CONSISTS OF 25 MULTIPLE CHOICE QUESTIONS (WORTH 1.6% EACH) TO BE ANSWERED ON THE SCANTRON EXAMINATION SHEET. INSTRUCTIONS ARE PROVIDED ON PAGE 2.

PART II IS WORTH 60% AND CONSISTS OF 6 QUESTIONS, SOME OF WHICH HAVE MULTIPLE CHOICE FORMAT WITHIN. READ THE QUESTIONS CAREFULLY. WRITE YOUR SOLUTIONS NEATLY IN THE SPACES PROVIDED. NO OTHER FORMAT WILL BE ACCEPTED.

NOTE: IT IS EXTREMELY IMPORTANT TO MAKE SURE YOUR SCANTRON SHEET IS PROPERLY COMLETED, OTHERWISE YOU WILL LOSE MARKS.

Remember to ENTER YOUR VERSION NUMBER, which can be found on the top right hand corner of this page, by filling in the BUBBLE in the "version" column provided. Finally, BUBBLE in your STUDENT number. Now CHECK all of your entries.

Q26	Q27	Q28	Q29	Q30	Q31	TOTAL	MC
10	12	12	12	6	8	60	

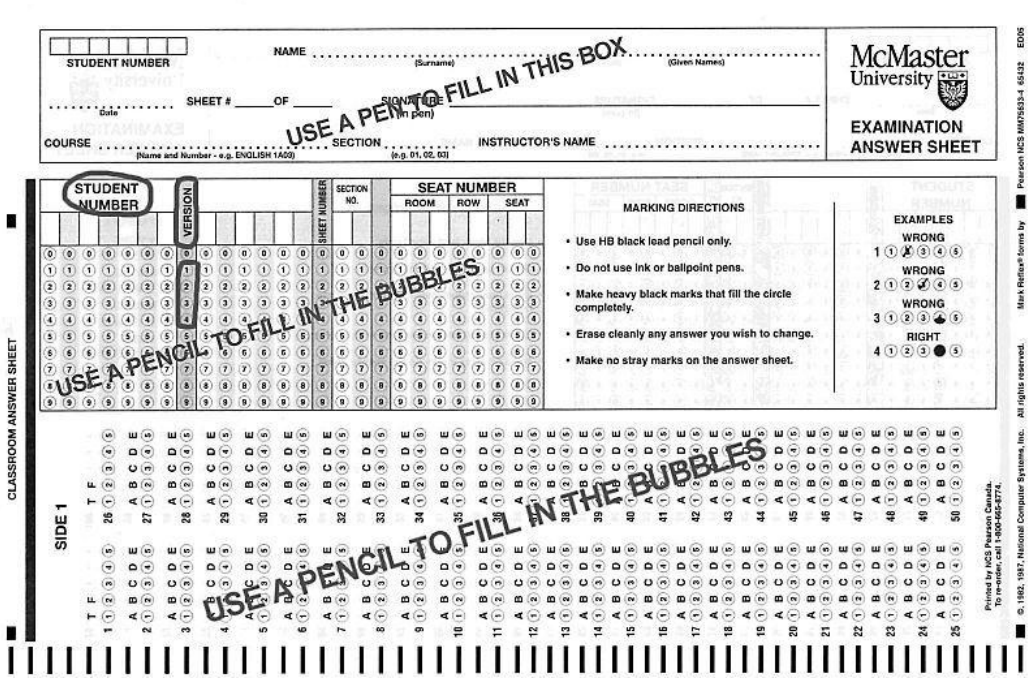
OMR EXAMINATION – STUDENT INSTRUCTIONS

Answer ALL the MC questions in Part I on optical scan sheets. You will not be penalized for incorrect answers. The MC questions are of equal value, and are worth a total of 40%. Failure to follow instructions below and on the optical scan sheets may result in loss of credit. Scan sheets will not be re-marked under any circumstances. You are responsible for ensuring all answers are in the correct place, and that you follow the correct procedure for filling out the scan sheet. **FILL IN THE BUBBLES DURING THE ALLOTTED EXAM TIME!**

NOTE: IT IS YOUR RESPONSIBILITY TO ENSURE THAT THE ANSWER SHEET IS PROPERLY COMPLETED. YOUR EXAMINATION RESULT DEPENDS UPON PROPER ATTENTION TO THESE INSTRUCTIONS.

The scanner, which reads the sheets, senses the bubble shaded areas by their non-reflection of light. **A heavy mark must be made, completely filling the circular bubble, with an HB pencil.** Marks made with a pen will **NOT** be sensed. Erasures must be thorough or the scanner will still sense a mark. Do **NOT** use correction fluid on the sheets. Do **NOT** put any unnecessary marks or writing on the sheet.

1. On SIDE 1 (**red side**) of the form, in the top box, print your student number, name, course name, and the date in the spaces provided, *in pen*. Then you **MUST** write your signature, in the space marked SIGNATURE.
2. In the second box, mark your **student number** and **test or exam version number (1, 2, 3 …)** by filling in the corresponding bubbles underneath, *in pencil*.
3. Answers: mark only **ONE** choice from the alternatives (A,B,C,D,E) provided for each question. The question number is to the left of the bubbles. Make sure that the number of the question on the scan sheet is the same as the number on the test paper. Begin answering Question # 1 of Part I of this exam using the first set of bubbles, marked "1". Do Not use Side 2.



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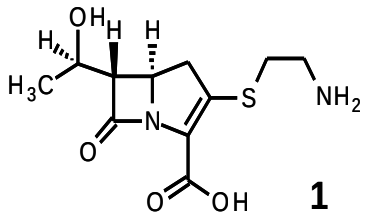
Part I

Begin answering questions using the first set of bubbles, marked "Side 1". **DO NOT USE SIDE 2.**

Questions 1-25; 40 marks total.

Questions 1-5 relate to thienamycin (compound 1), which is a member of the penicillin family of antibiotics. The structure is shown alongside:



1

1. How many sp^2 hybridized carbon atoms are present in compound **1**?

(A) 1 (B) 2 (C) 3 (D) 4 (E) 5

2. How many **carbon-based** chirality centres are present in compound **1**?

(A) 1 (B) 2 (C) 3 (D) 4 (E) 5

3. Compound **1** contains:

(A) A primary amine and primary amide
(B) A tertiary amine and primary amide
(C) A tertiary amine and tertiary amide
(D) A primary amine and tertiary amide
(E) A secondary amine and secondary amide

4. The pK_a of the most acidic group in **1** is approximately:

(A) 20
(B) 16
(C) 10
(D) 4
(B) -7

5. Which of the following statements is/are true about the proton nmr spectrum of **1**:

(i) The methyl group in compound **1** gives a doublet;
(ii) The CH_2 group next to sulfur in compound **1** appears as a triplet;
(iii) The proton of the CO_2H group will appear as a broad singlet

(A) i (B) ii (C) iii (D) i and ii (E) i, ii and iii

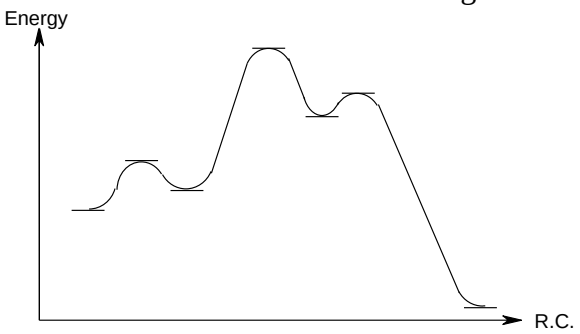
Continued on next page

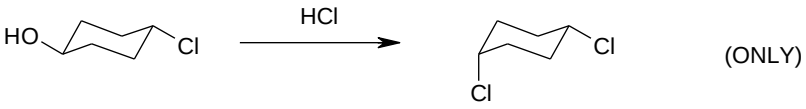
6. Which of the following statement(s) is(are) TRUE?

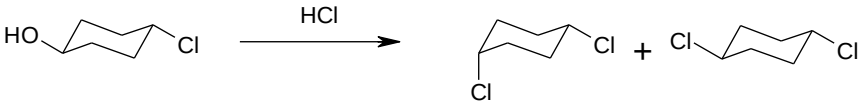
i) Double bonds (alkenes) with more carbon substituents are more stable than their isomers with more H substituents.
ii) There are 2 double bonds or rings in a compound with molecular formula C_4H_7Cl
iii) Alkenes normally act as electrophiles
iv) π bonds are stronger than σ bonds

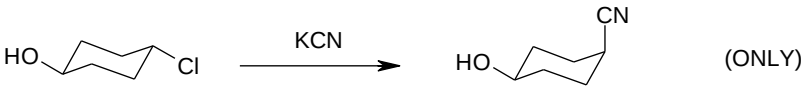
(A) i (B) i and ii (C) iii (D) ii and iv (E) iv

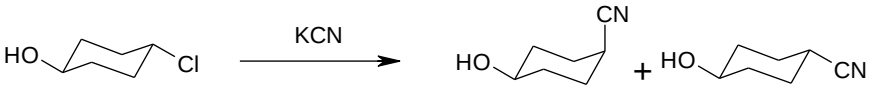
7. The reaction co-ordinate diagram shown below corresponds to which reaction?



(A) 

(B) 

(C) 

(D) 

(E) None of the above; the reaction must involve a rearrangement

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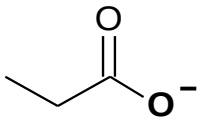
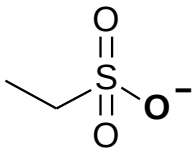
8. Which of the following statement(s) about carbocations is(are) TRUE?

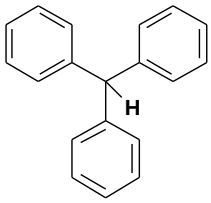
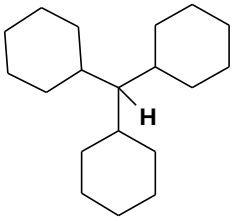
i) starting from an alkyl halide, the activation energy to form a primary carbocation is larger than the activation energy to form a secondary carbocation
ii) primary carbocations are better stabilized by H-C hyperconjugation than tertiary carbocations
iii) the rate of an S_N1 reaction is determined by the activation energy for nucleophilic attack at the carbocation
iv) the benzyl cation is more stable than the phenyl cation because of resonance stabilization.

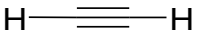
(A) i (B) i and iv (C) ii and iii (D) ii (E) iii

9. Which of the following statement(s) is(are) FALSE?

i) Methoxide (MeO^-) is more nucleophilic than *tert*-butoxide (Me_3CO^-)

ii)  is more basic than 

iii)  is more acidic than (only consider the H's shown) 

iv) H_2 is more acidic than 

(A) i (B) i and ii (C) ii and iii (D) ii and iv (E) iv

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10. The following sentence has the format "Statement 1 BECAUSE Statement 2".

Decide whether statement 1 is true, whether statement 2 is true, and whether the REASONING (the 'because' relationship) between them is valid.

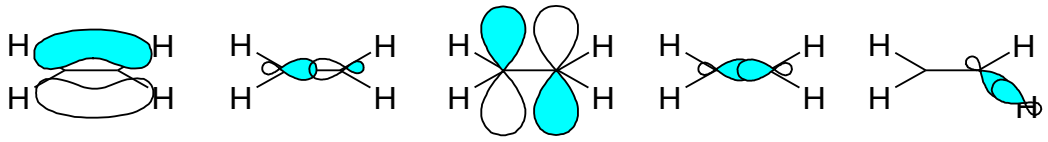
Statement 1: "Carbocations follow the stability order tertiary > secondary > primary, but the order is REVERSED for carbanions"

BECAUSE

Statement 2: "Carbocations, being electron-deficient, are stabilized by alkyl groups, whereas carbanions have excess electron density and are destabilized by alkyl groups".

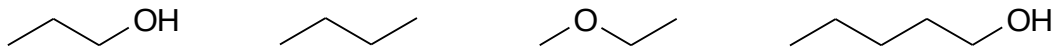
(A) Statement 1 and Statement 2 are both correct, and the reasoning is valid.
(B) Statement 1 and Statement 2 are both correct, but the reasoning is NOT valid.
(C) Statement 1 is correct, but Statement 2 is NOT correct.
(D) Statement 1 is NOT correct, but Statement 2 is correct.
(E) Statement 1 and Statement 2 are both NOT correct

11. Which of the following diagrams best represents the C-H σ molecular orbital of ethene?



(A) **(B)** **(C)** **(D)** **(E)**

12. Arrange the following compounds in order of INCREASING solubility in water:



i **ii** **iii** **iv**

(A)	least soluble	i < ii < iii < iv	most soluble
(B)	least soluble	ii < i < iv < iii	most soluble
(C)	least soluble	ii < iii < iv < i	most soluble
(D)	least soluble	ii < iii < i < iv	most soluble
(E)	least soluble	i < iv < iii < ii	most soluble

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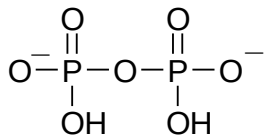
13. How many EQUIVALENT resonance forms can be drawn for the diphosphate di-anion, including the one shown?



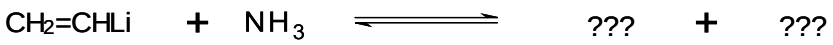
(A) 3 (B) 4 (C) 5 (D) 6 (E) 7

14. Under appropriate conditions, the reaction of an acetylide (i.e. alkynide) anion with an alkyl halide is an effective way to create a new carbon-carbon bond. Indicate the CORRECT statements about this reaction from the list below:

(i) Polar protic solvents can be used to increase the rate of this reaction
(ii) This process works best for a primary alkyl halide
(iii) This reaction fails with a tertiary alkyl halide because of competing elimination
(iv) This reaction works for alcohols as well as alkyl halides
(v) This reaction works best when it is heated to a high temperature

(A) i, iv **(B)** i, ii, iii, iv **(C)** ii, iii, v **(D)** ii, iii **(E)** iii, iv, v

15. Consider the reaction of the alkenylithium reagent MeLi with liquid ammonia:



The equilibrium constant for this reaction is approximately:

(A) 10^{-44} (B) 10^{-6} (C) 10^{+6} (D) $10^{+9.24}$ (E) 10^{+44}

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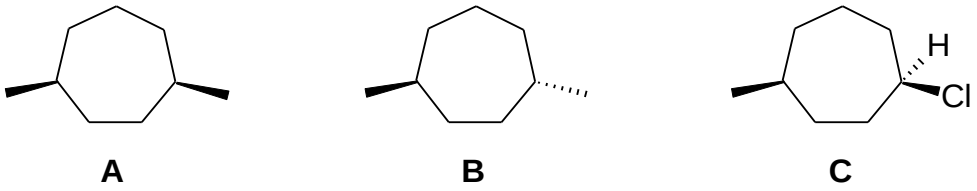
16. Which statement(s) is(are) FALSE?

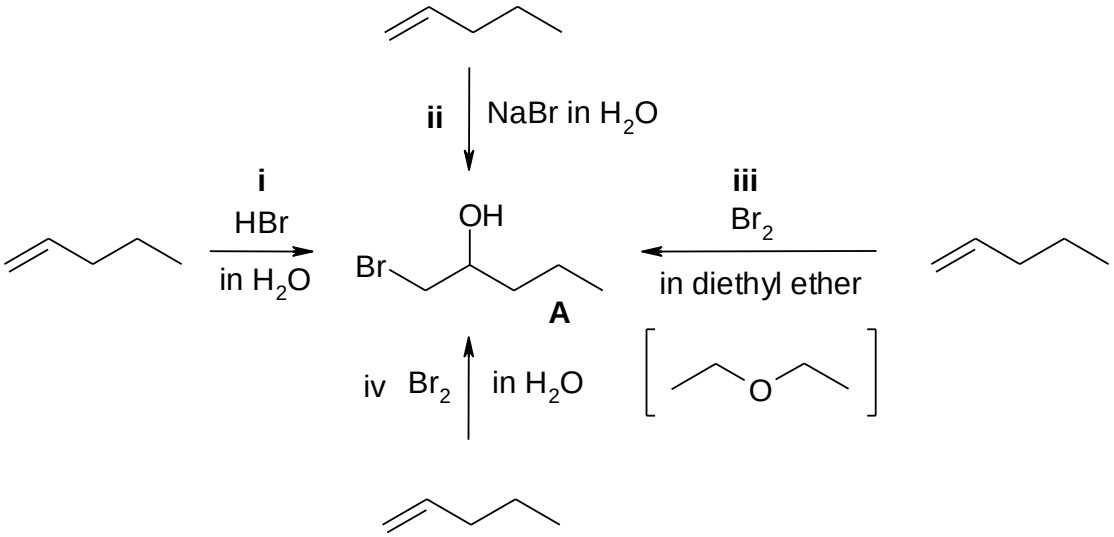


A **B** **C**

i) All three compounds have stereogenic centres
ii) Both compounds A and B are achiral (that is, not chiral).
iii) In compound C, the carbon bearing Cl is *R*.
iv) Compound A is a meso compound

(A) i (B) ii (C) iii (D) iv (E) none are false

17. What is the best way to make halohydrin compound **A**?



(A) i (B) ii (C) iii (D) iv (E) none of the routes will lead to compound **A**

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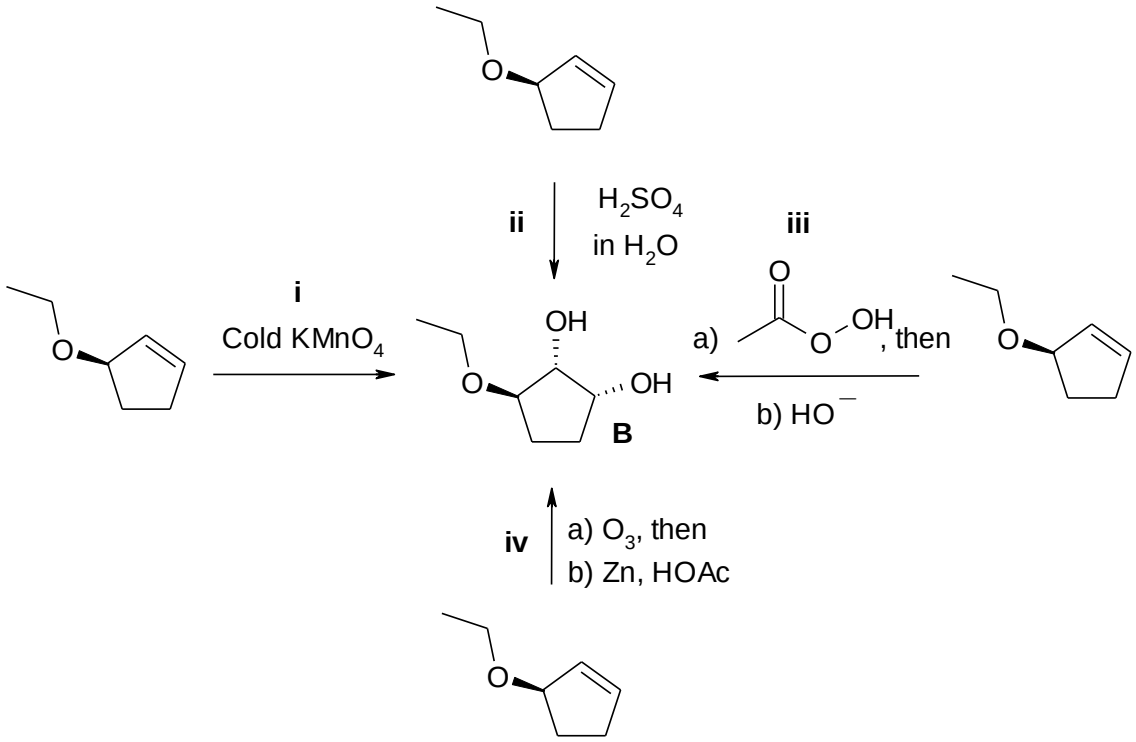
18. What is the best way to make diol compound **B**?



(A) i (B) ii (C) iii (D) iv (E) none of the routes will lead to compound **B**

19. A compound of molecular formula C_5H_8 was reacted with hot $KMnO_4$ and HO^- to give **ONLY** 2 compounds: one containing 2 carbons and one containing 3 carbons. Which of the following statements is correct?

i) the compound could be a cyclic alkene
ii) the compound could be a linear alkene (only one double bond)
iii) the compound could be 1,3-pentadiene
iv) the compound could be 2-pentyne

(A) i (B) ii (C) iii (D) iv (E) none are possible

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20. Indicate the CORRECT statement(s) below regarding the fundamental equations of thermodynamics and kinetics that govern organic chemistry:

i. In an equilibrium mixture of products and reactants, for a reaction that has a negative value of ΔS and a positive value of ΔH, the products are favoured
ii. Heating many reaction mixtures up by $10^{o}C$ will result in the rate increasing by a factor of about 10
iii. In most substitution reactions, the position of the equilibrium between starting materials and products is dominated by the enthalpy change of the reaction
iv. The rate equation for an S_N2 reaction has the form - d[S]/dt = k [S], where S is the organic starting material

(A) None are correct (B) *i* (C) *ii* (D) *iii* (E) *iv*

21. The hydroboration reaction of (*E*)-3-methyl-2-pentene proceeds in the following manner:

(A) Markovnikov and anti
(B) Markovnikov and syn
(C) Anti-Markovnikov and anti
(D) Anti-Markovnikov and syn
(E) Non-selective

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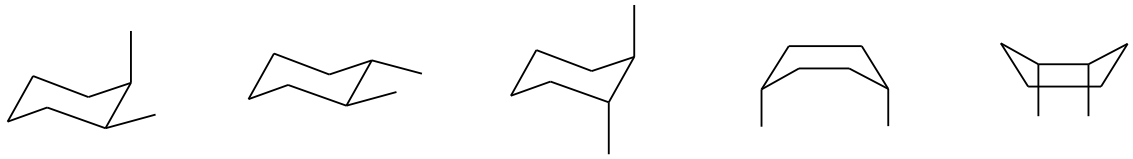
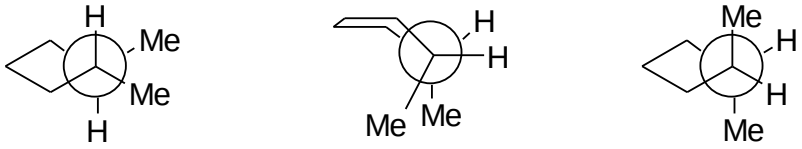
22. Shown below are several representations of structures of dimethylcyclohexane. The conformational representations are marked i-v, while the Newman projections are labeled X, Y and Z:



i **ii** **iii** **iv** **v**

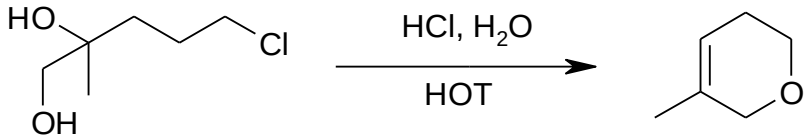


X **Y** **Z**

Structures **X**, **Y** and **Z** correspond, respectively, to:

	X	**Y**	**Z**
(A)	i	Ii	iii
(B)	ii	Iii	v
(C)	ii	V	iii
(D)	iii	V	ii
(E)	ii	Iv	iii

23. Consider the following reaction, which involves a sequence of two reactions we have studied in this course:



The mechanisms of these two steps are:
(A) S_N2 and E2
(B) S_N2 and E1
(C) S_N1 and E2
(D) S_N1 and E1
(E) S_N1 and S_N1

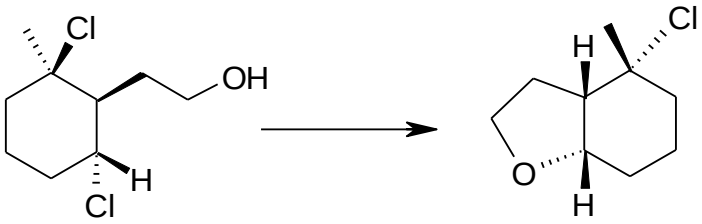
 Continued on next page

24. Indicate the CORRECT statements below:

(i) The process of resolution can be used to separate diastereomers but not enantiomers
(ii) In resolution, a racemic compound is used to separate another racemate
(iii) In one method of resolution, a pure enantiomer of reagent **A** is used to form salts with a racemic mixture; the resulting salts are diastereomeric and can be separated
(iv) A pair of enantiomers cannot be separated on silica gel chromatography, but can be separated on a stationary phase that is chiral

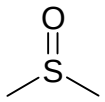
(A) i, ii, iv **(B)** i, iii **(C)** ii, iv **(D)** iii, iv **(E)** ii, iii, iv

25. Suppose you want to accomplish the following transformation. Decide which reaction and mechanism is needed, then choose which of the following conditions would best favor forming the desired product over others, and gives it at the fastest rate:



(A) NaH, cold DMSO
(B) NaH, cold H_2O
(C) NaH, hot DMSO
(D) Conc hot HCl in H_2O
(E) Solvolysis with H_2O

The structure of DMSO is



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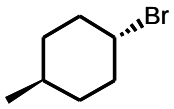
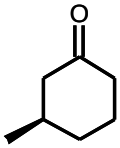
Part II: Answer in the spaces provided

26. [10] Draw the MAJOR ORGANIC product or products of each of the reactions shown below.

You must show the correct functional group(s), constitutional isomer(s), and stereochemistry where needed. Although two boxes are provided, not every reaction will have more than one product: Use these two boxes to show isomers (e.g., stereoisomers including enantiomers, where appropriate), or in (c) to show the sequential products. Fill in the boxes provided; no other answers will be marked.

(A) 

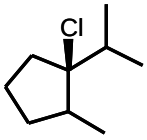
KCN, diethyl ether
room temp.

(B) 

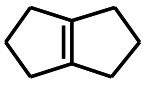
1. $NaBH_4$, MeOH
2. H_3O^+,H_2O workup

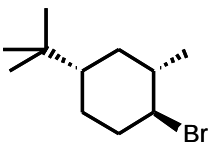
(C) 
1. NaH 2. MeBr
HBr
(2 equiv.)

(D) 
H_2
$Pd/BaSO_4$/quinoline
(Lindlar catalyst)

(E) 

H_2O
heat

(F) 
1. O_3
2. Zn/HOAc

(G) 

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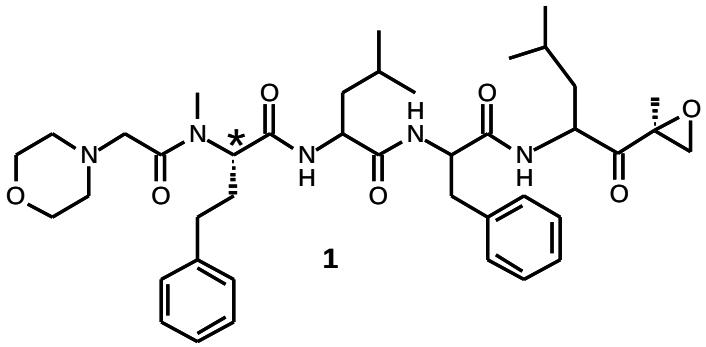
27. [12] This question is about the properties of Kyprolis (compound **1**), shown below; this compound was recently approved for treatment of cancers (multiple myeloma). Answer each question about this compound in the spaces provided below.

PART A: This part deals with the structure of Kyprolis.

(i) On the structure shown, CIRCLE and LABEL the specific types of nitrogen-containing and/or oxygen-containing functional groups that are present in **1**. (e.g. primary amide, alcohol, etc.). Do NOT include any secondary amides.

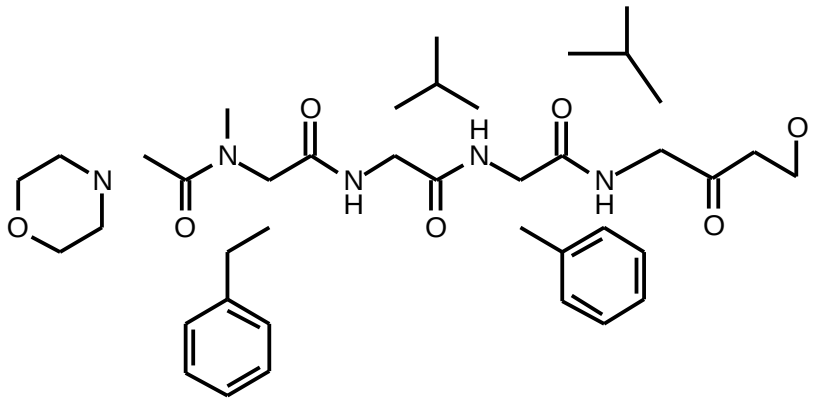


1

(ii) How many carbon-based chirality centres are present in **1**?

(iii) Give the absolute configuration of the chirality centre marked with a * in the structure above.

(iv) Draw the isomer of **1** that has (*S*) absolute configuration at each chiral centre, using wedges and dashed bonds to show the substituents at each chiral centre (do NOT include the hydrogens); use ordinary lines to complete bonds at any achiral centre. Use the template below to complete your structure:



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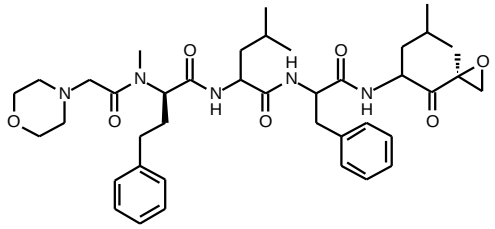
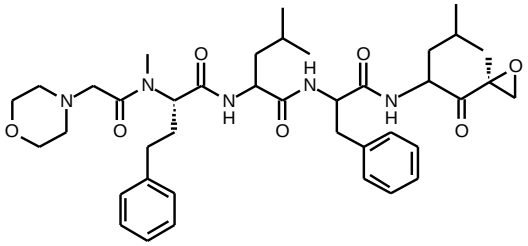
(v) The structure shown alongside is: (CIRCLE ONE)



Identical to **1** | A racemic mixture | A meso compound | An enantiomer of **1** | A diastereomer of **1**

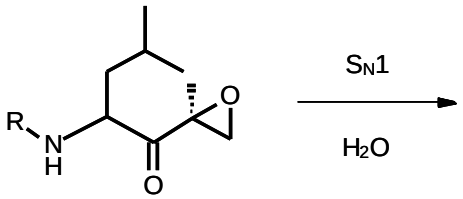
(vi) On the structure alongside: CIRCLE the most basic site in **1**; and place a square around the component with the greatest angle strain.



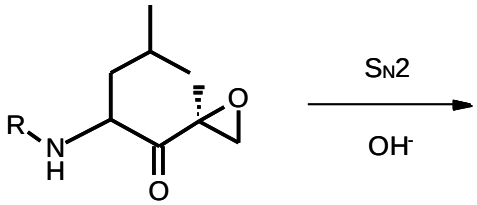
PART B: This part deals with the reactions of Kyprolis (1)

Compound **1** is biologically active because it can react with biological nucleophiles, giving rise to SUBSTITUTION products; consider attack at the right-hand part of **1** (drawn below).

(vii) Show, with a mechanism drawn on the template below, how a nucleophile would attack this component in an S_N1 reaction, AND draw the structure of the product:



(viii) Show, with a mechanism drawn on the template below, how a nucleophile would attack this component in an S_N2 reaction AND draw the structure of the product:

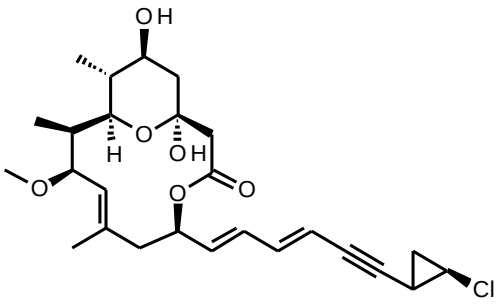


(ix) What OTHER atom in which OTHER functional group in the partial structure of **1** above is also electrophilic?

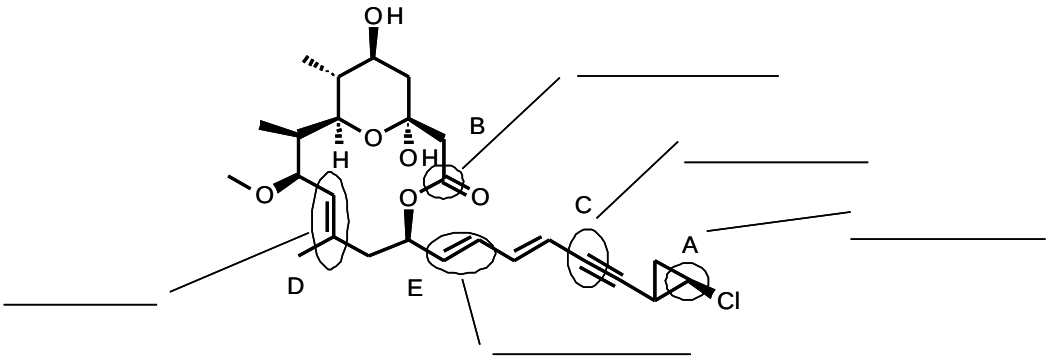
ANSWER: The _____ atom in the _____ group.

 Continued on next page

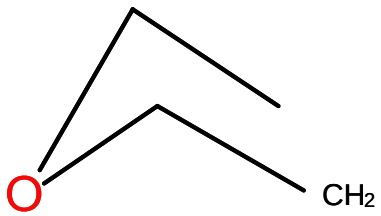
28. [12] The calipeltosides are natural products that have anti-HIV activity. Structure **2** alongside shows the core of these natural products (the active structures have sugars attached). Answer the following questions related to the structure **2**.



(i) On the structure below, indicate the hybridization of atoms marked A-C, AND indicate whether groups D and E are conjugated or non-conjugated:



(ii) Consider the six-membered ring in **2**. Complete the following template to correctly draw the chair conformation, with proper positions of all the substituents in **2**. LABEL the secondary hydroxyl group as axial or equatorial. (Use "R" for the large ring; you MUST place the CH_2 where shown)



(iii)What is the **relationship** (cis, etc.), **within the 6-membered ring you have drawn above,** between:

(a) The two hydroxyl groups: _____

(b) The two substituents ("R") that compose the large-size ring: _____

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(iv)(a) How many (non-hydrogen) substituents are axial in your structure in (ii)?

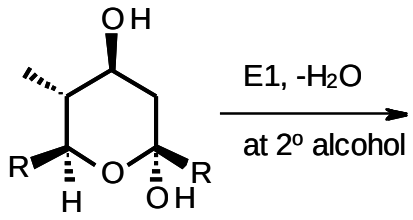
(b) How many would be axial in the alternate chair conformer?

(c) CIRCLE which of the two would be more stable:

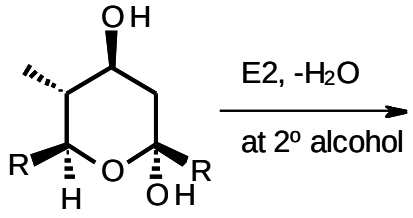
The original one shown The alternate one in (b) above

(v) Draw the MAJOR organic product of acid-catalyzed elimination of the **secondary alcohol** in the structure shown below, under:

(a) E1 conditions



(b) E2 conditions



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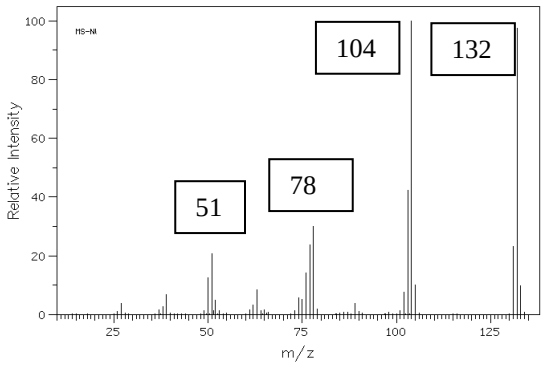
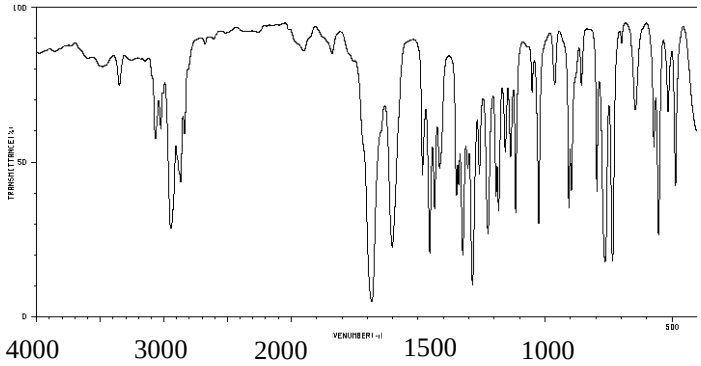
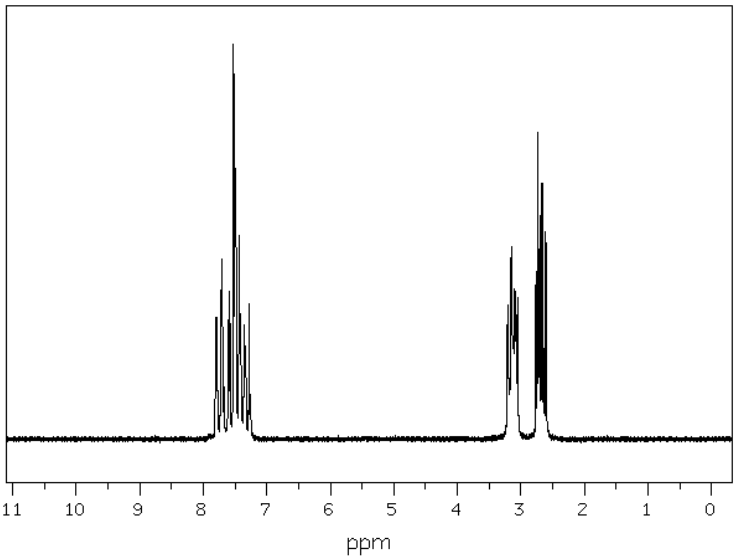
29. [12] This question requires you to answer a series of questions aimed at identifying an unknown compound (**1**).

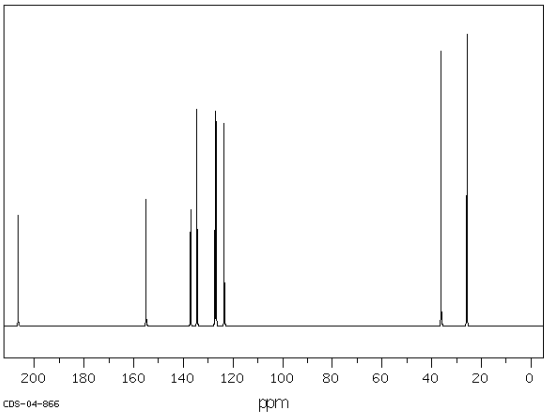
- The mass spectrum, IR spectrum, and proton and ^{13}C NMR spectra are provided, and RELATIVE integrals and multiplicities are given above the proton NMR:





Integral:	1	3	2	2
# Lines (multiplicity):	2	Many	3	3





(NOTE: Expansion around δ 120-150: shows 6 lines)

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(i) From the mass spectrum, deduce the molecular mass of the unknown compound. Is there any evidence that any halogen groups are present, and if so which signals show is this evidence? Answer by completing the boxes and spaces below.

Mass? _____

	Yes	No	Evidence
Halogens?	□	□	_____

(i) Is an aromatic ring likely present, and how could you tell from the NMR spectra?

	Yes	No	Evidence (chemical shift) Proton	Carbon-13
Aromatic?	□	□	_____	_____

(ii) List ALL the evidence for the presence or absence of (a) carbonyl group(s).

	Present? Yes	No	Evidence (chemical shift or frequency)
IR?	□	□	_____
^{13}C-nmr?	□	□	_____

(iii) How many carbon atoms are likely present? How many protons?

Carbons? _____ Protons? _____

(iv) Determine the molecular formula for compound **1**. How many degrees of unsaturation are present in compound **1**?

Formula: _____ Degrees of unsaturation: _____

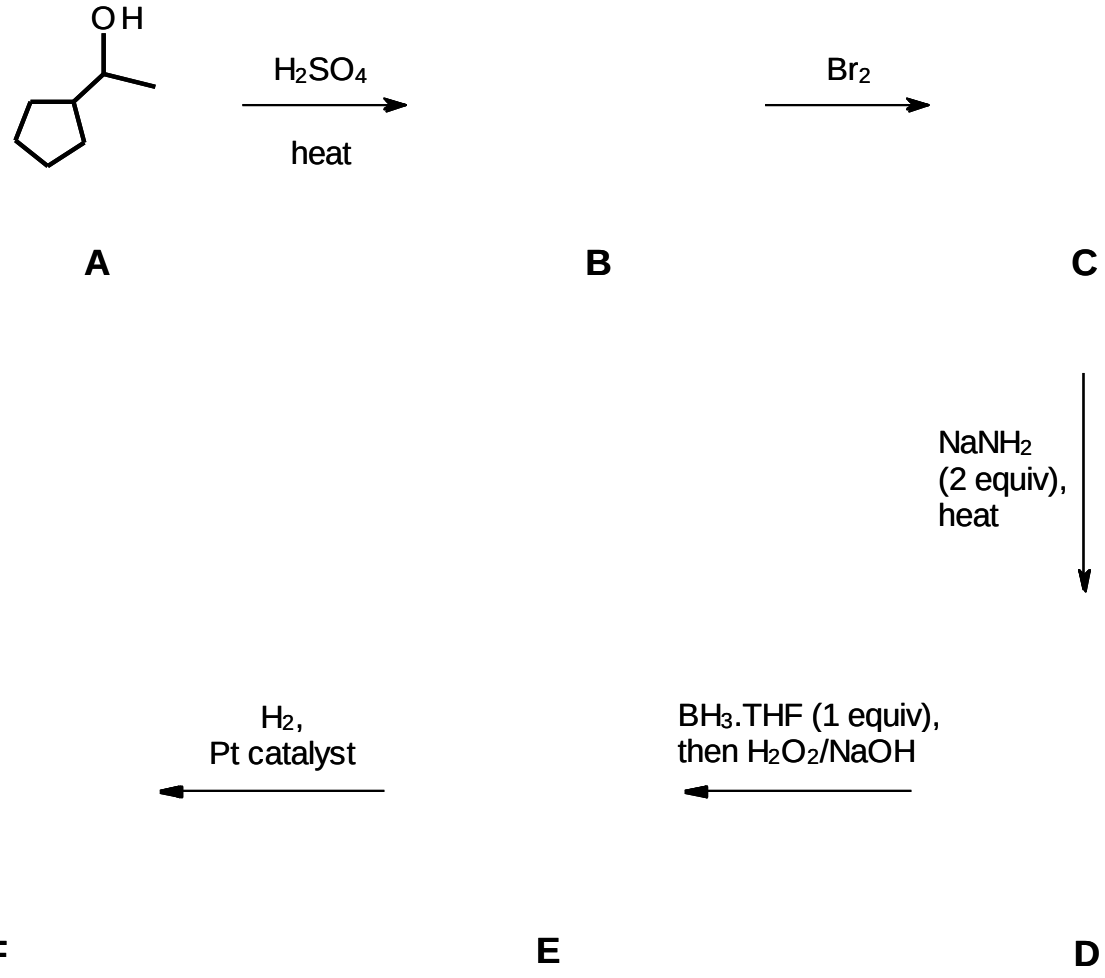
(v) What can you deduce from the **multiplicities** of the proton nmr signals at 2.5-3.5 ppm in compound **1**?

(vi) Draw the most likely structure of the unknown molecule, given the above spectroscopic information.

 Continued on next page

30. [6] The synthetic reaction scheme shown below involves a synthesis of an alcohol, starting with 1-cyclopentyl-ethanol (A).

(a) Draw the products (B-F) of the five reaction steps in the spaces provided, in the same orientation as the starting material.



(b) This synthesis can be reduced to 3 or less reaction steps. Suggest a series of reagents (a,b, and c if necessary) that would accomplish the same overall transformation, i.e. A to F:

a.

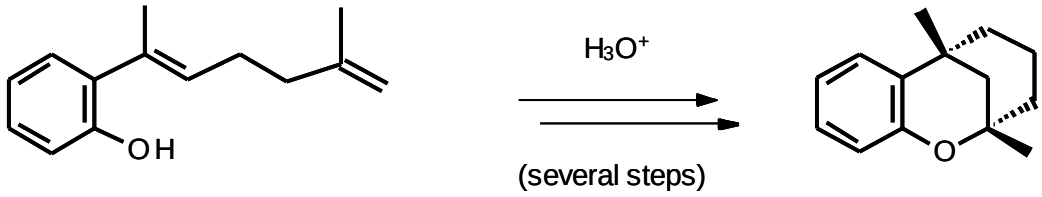
b.

c.

 Continued on next page

31. [8] When a compound contains two functional groups and both can react with a reagent, it can be difficult to predict which will react fastest, but often one of them reacts faster, and a single product is obtained.

(a) In the case below, a reaction used in the synthesis of the natural product heliol, think carefully about which functional group reacts first, and propose a mechanism for this reaction, showing EVERY STEP and INTERMEDIATE, ALL correct curly arrows and charges, and lone pairs where they are involved in the step in question. Start with the structure provided: you do not have to re-draw this compound. Do not worry about stereochemistry for this question.



(b) A chemist performed this reaction, and obtained a mixture of the starting material (**A**), the product shown above (**B**), and some by-product (**C**) which resulted from hydration of the alkene starting material. They separated these by chromatography on silica gel. Arrange these compounds in the expected order of elution from the column (answer with letters A, B and C):

First to elute	Second	Last
ANSWER: _____	_____	_____

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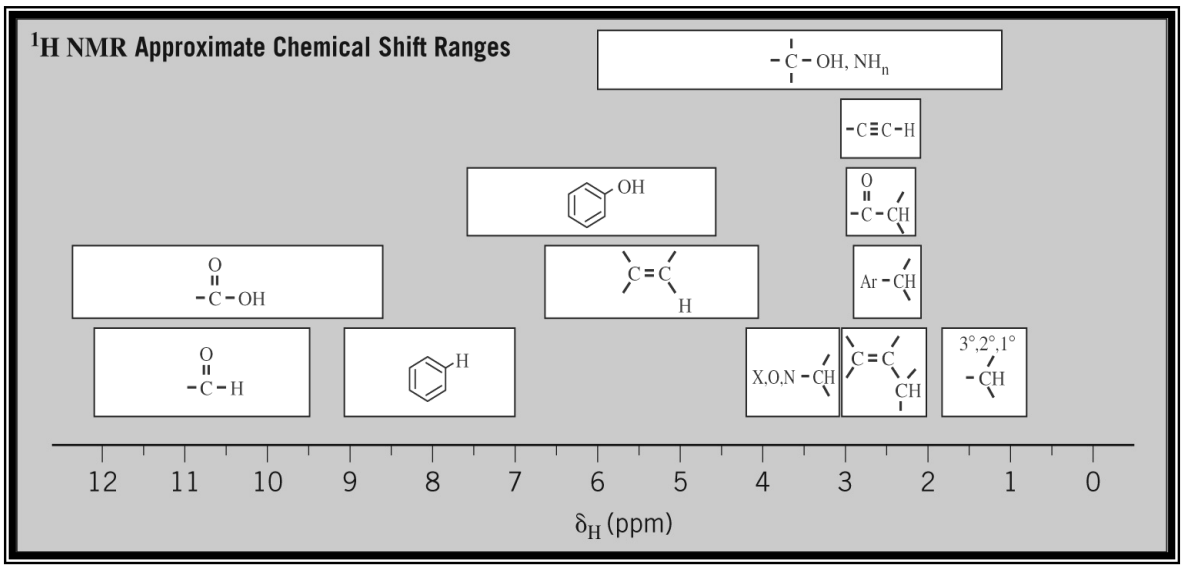
Acid	pK_a
*H*I	-9
*H*Br	-8
*H*Cl	-7
H_2SO_4	-5.2
H_3O^+	-1.74
H_3PO_4	2.1
CH_3CO_2H	4.76
H_2CO_3	6.36
NH_4^+	9.24
HCO_3^-	10.33
H_2O	15.7
CH_3CH_2OH	15.9
$CH_3C{=}OMe$	20
$HC{\equiv}CH$	25
H_2	35
NH_3	38
$CH_2{=}CH_2$	44
CH_3CH_3	51



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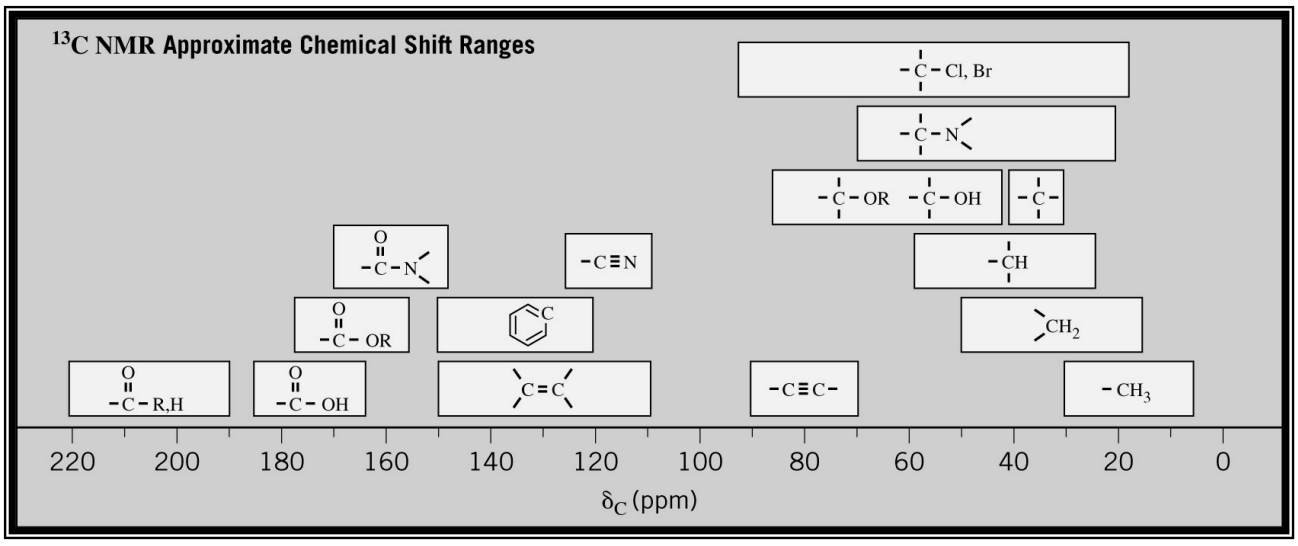
PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.008																	2 He 4.002
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 24.30											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.38	26 Fe 55.85	27 Co 58.93	28 Ni 58.70	29 Cu 63.55	30 Zn 65.39	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 127.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 181.0	74 W 183.8	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 227.0	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun								

58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce 140.1	Pr 140.9	Nd 144.2	Pm 145	Sm 150.4	Eu 152.0	Gd 157.3	Tb 158.9	Dy 162.5	Ho 164.9	Er 167.3	Tm 168.9	Yb 173.0	Lu 175.0
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



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IR correlation chart:

Group		Frequency Range (cm^{-1})	Intensity[a]
A. Alkyl			
C—H (stretching)		2853–2962	(m–s)
Isopropyl, —$CH(CH_3)_2$		1380–1385	(s)
	and	1365–1370	(s)
tert-Butyl, —$C(CH_3)_3$		1385–1395	(m)
	and	~1365	(s)
B. Alkenyl			
C—H (stretching)		3010–3095	(m)
C═C (stretching)		1620–1680	(v)
R—CH═CH_2	(out-of-plane C—H bendings)	985–1000	(s)
	and	905–920	(s)
R_2C═CH_2		880–900	(s)
cis-RCH═CHR		675–730	(s)
trans-RCH═CHR		960–975	(s)
C. Alkynyl			
≡C—H (stretching)		~3300	(s)
C≡C (stretching)		2100–2260	(v)
D. Aromatic			
Ar—H (stretching)		~3030	(v)
Aromatic substitution type			
(C—H out-of-plane bendings)			
Monosubstituted		690–710	(very s)
o-Disubstituted	and	730–770	(very s)
m-Disubstituted		735–770	(s)
		680–725	(s)
	and	750–810	(very s)
p-Disubstituted		800–860	(very s)
E. Alcohols, Phenols, and Carboxylic Acids			
O—H (stretching)			
Alcohols, phenols (dilute solutions)		3590–3650	(sharp, v)
Alcohols, phenols (hydrogen bonded)		3200–3550	(broad, s)
Carboxylic acids (hydrogen bonded)		2500–3000	(broad, v)
F. Aldehydes, Ketones, Esters, and Carboxylic Acids			
C═O (stretching)		1630–1780	(s)
Aldehydes		1690–1740	(s)
Ketones		1680–1750	(s)
Esters		1735–1750	(s)
Carboxylic acids		1710–1780	(s)
Amides		1630–1690	(s)
G. Amines			
N—H		3300–3500	(m)
H. Nitriles			
C≡N		2220–2260	(m)

[a]Abbreviations: s = strong, m = medium, w = weak, v = variable, ~ = approximately.

THE END