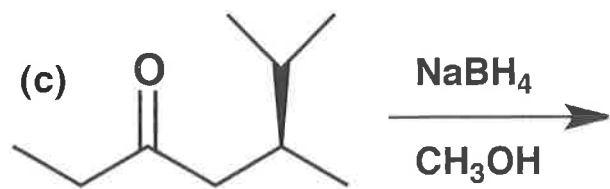
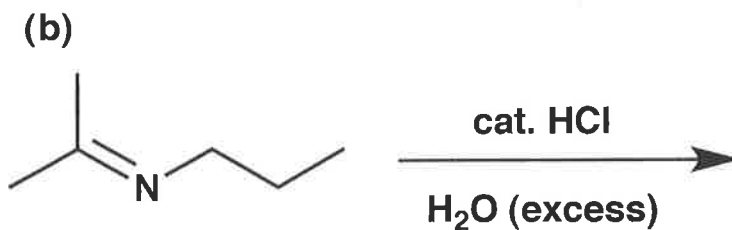
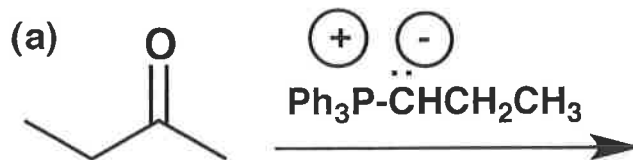


General Instructions:

- (i) Use scratch paper at back of exam to work out answers; final answers must be recorded at the proper place on the exam itself for credit. Models are allowed.
- (ii) Print your name on each page.
- (iii) Please keep your paper covered and your eyes on your own work. No electronic devices may be used. Misconduct will lead to failure in the course.

1. (20 points) Show the product(s) expected from the reactions indicated below.



(single enantiomer)

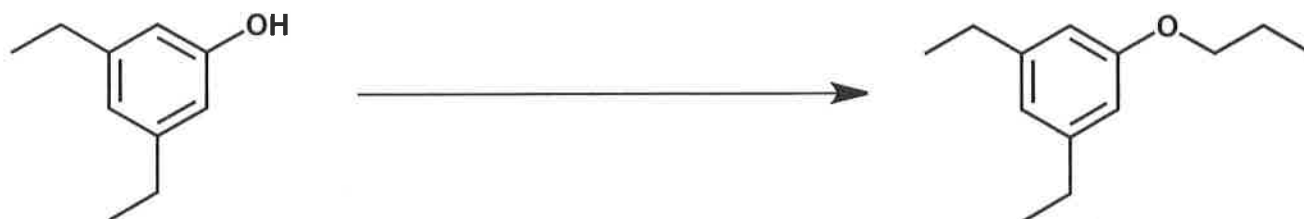
Name _____

2. (20 points) Show the reagents and other organic molecules required to convert the starting material to the indicated product. Be sure to differentiate clearly between distinct steps, by using "1)", "2)", etc. over or under the arrow.

(a)



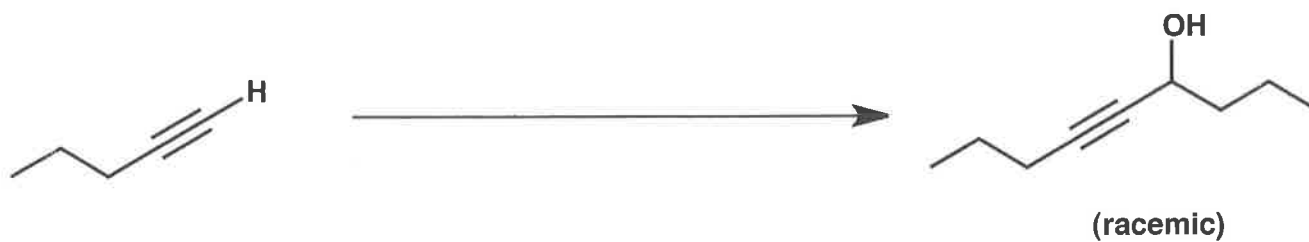
(b)



(c)

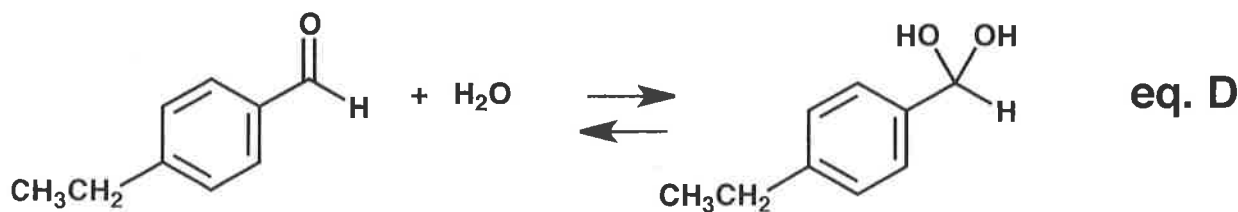
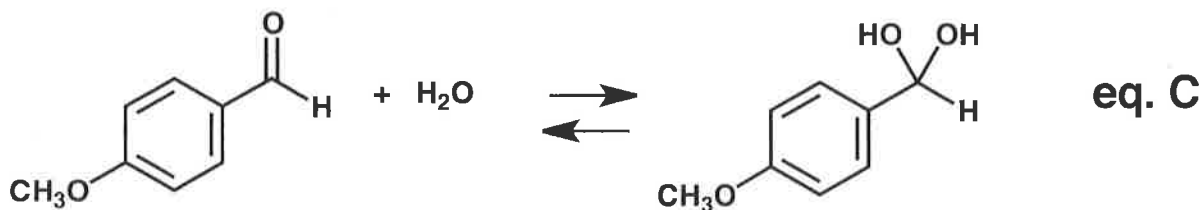
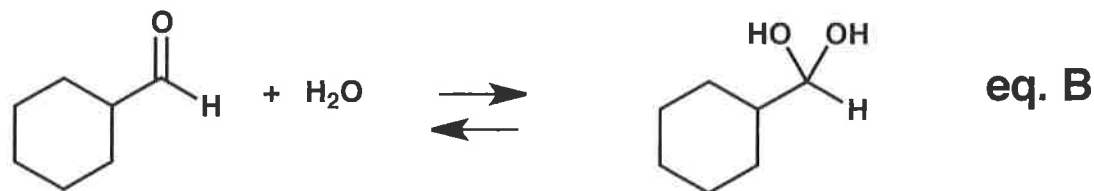
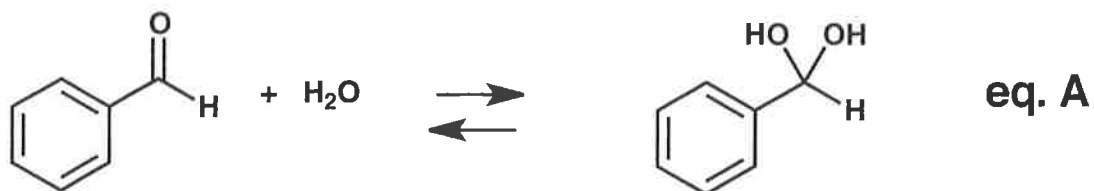


(d)



Name _____

3. (8 points) Rank the four equilibria below (A, B, C and D) in terms of the extent to which the RIGHT side will be favored, from least to most.

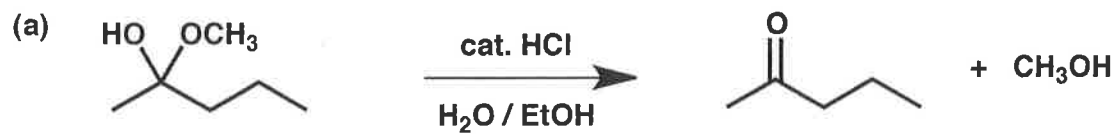


INCREASING tendency to lie to the RIGHT:

_____ < _____ < _____ < _____

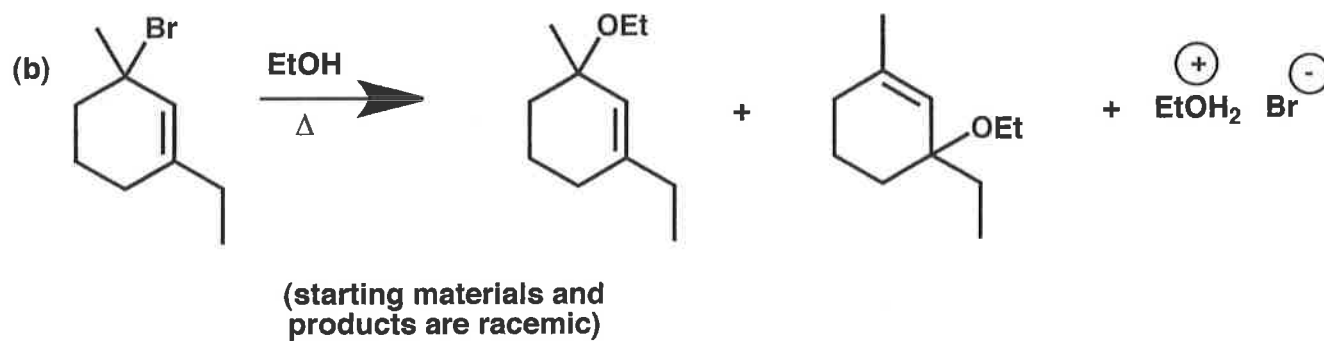
[Place the letters A, B, C and D in the blanks above, in the proper order.]

4. (17 points) Provide a mechanism (curved arrows) for each reaction shown below. Draw all important resonance structures for intermediates.



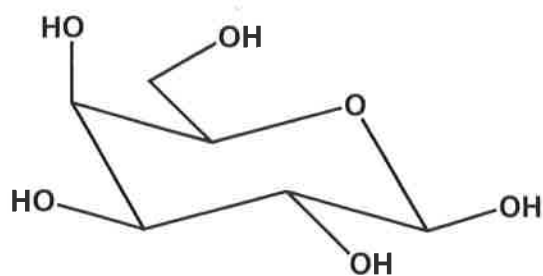
(cont. on next page)

4. (cont.)



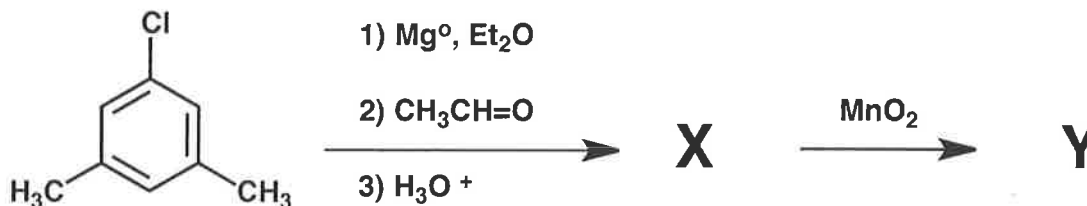
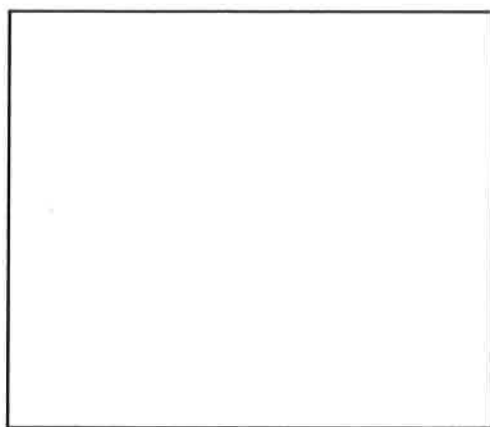
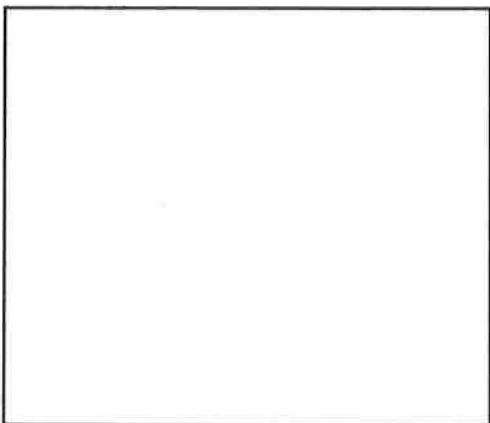
Name _____

5. (6 points) Shown below is one of the naturally occurring forms of the carbohydrate designated galactose. CIRCLE each carbon atom, and next to each circle indicate the carbon atom's oxidation state, as defined in lecture.



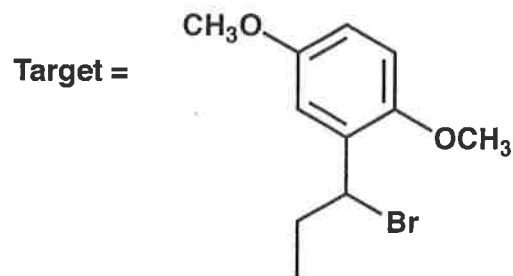
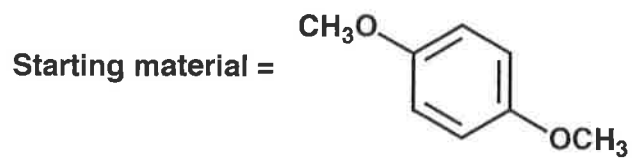
Name _____

6. (14 points) Show the structures of molecules X and Y in the appropriate boxes. The structures you propose should be consistent with the reactions shown and the spectroscopic data provided.

**X =**Partial spectroscopic data:IR: Strong band in range 3250-3350 cm^{-1} ^{13}C NMR: Seven resonances ^1H NMR: Six resonances, one of which is lost upon shaking with D_2O .**Y =**Partial spectroscopic data:IR: Strong band in range 1680-1690 cm^{-1} ^{13}C NMR: Seven resonances ^1H NMR: Four resonances; none is lost upon shaking with D_2O .

Name _____

7. (15 points) Propose an efficient synthetic route from the indicated starting material to the target. You may use any other starting materials and reagents.



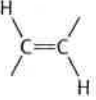




<u>Problem #</u>	<u>Score</u>
1	/ 20
2	/ 20
3	/ 8
4	/ 17
5	/ 6
6	/ 14
7	/ 15

Total: / 100

Periodic Table of the Elements

		¹ H 1.008																		² He 4.003											
																				⁹ F 19.00		¹⁰ Ne 20.18									
																				¹⁶ S 32.06		¹⁷ Cl 35.45		¹⁸ Ar 39.95							
																				³² Ge 72.59		³³ As 74.92		³⁴ Se 78.96		³⁵ Br 79.90		³⁶ Kr 83.80			
																				⁴⁹ In 114.82		⁵⁰ Sn 118.69		⁵¹ Sb 121.75		⁵² Te 127.60		⁵³ I 126.90		⁵⁴ Xe 131.30	
																				⁸¹ Tl 204.37		⁸² Pb 207.19		⁸³ Bi 208.98		⁸⁴ Po (209)		⁸⁵ At (210)		⁸⁶ Rn (222)	
																				¹⁰⁸ Uno* (265)		¹⁰⁹ Una* (266)									
																				¹⁰⁷ Uns* (262)		¹⁰⁸ Uno* (265)									
																				¹⁰⁶ Unh* (263)		¹⁰⁷ Uns* (262)									
																				¹⁰⁵ Unp* (262)		¹⁰⁶ Unh* (263)									
																				¹⁰⁴ Unq* (261)		¹⁰⁵ Unp* (262)									
																				¹⁰³ Unl* (261)		¹⁰⁴ Unq* (261)									
																				¹⁰² Unk* (260)		¹⁰³ Unl* (261)									
																				¹⁰¹ Unj* (259)		¹⁰² Unk* (260)									
																				¹⁰⁰ Uni* (258)		¹⁰¹ Unj* (259)									
																				⁹⁹ Uuh* (257)		¹⁰⁰ Uni* (258)									
																				⁹⁸ Uuq* (256)		⁹⁹ Uuh* (257)									
																				⁹⁷ Uuo* (255)		⁹⁸ Uuq* (256)									
																				⁹⁶ Uuo* (254)		⁹⁷ Uuo* (254)									
																				⁹⁵ Uub* (253)		⁹⁶ Uuo* (254)									
																				⁹⁴ Uua* (252)		⁹⁵ Uub* (253)									
																				⁹³ Uu* (251)		⁹⁴ Uua* (252)									
																				⁹² Uu* (250)		⁹³ Uu* (251)									
																				⁹¹ Uu* (249)		⁹² Uu* (250)									
																				⁹⁰ Uu* (248)		⁹¹ Uu* (249)									
																				⁸⁹ Uu* (247)		⁹⁰ Uu* (248)									
																				⁸⁸ Uu* (246)		⁸⁹ Uu* (247)									
																				⁸⁷ Uu* (245)		⁸⁸ Uu* (246)									
																				⁸⁶ Uu* (244)		⁸⁷ Uu* (245)									
																				⁸⁵ Uu* (243)		⁸⁶ Uu* (244)									
																				⁸⁴ Uu* (242)		⁸⁵ Uu* (243)									
																				⁸³ Uu* (241)		⁸⁴ Uu* (242)									
																				⁸² Uu* (240)		⁸³ Uu* (241)									
																				⁸¹ Uu* (239)		⁸² Uu* (240)									
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																				⁷⁸ Uu* (236)		⁷⁹ Uu* (237)									
																				⁷⁷ Uu* (235)		⁷⁸ Uu* (236)									
																				⁷⁶ Uu* (234)		⁷⁷ Uu* (235)									
																				⁷⁵ Uu* (233)		⁷⁶ Uu* (234)									
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																				⁷³ Uu* (231)		⁷⁴ Uu* (232)									
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																				⁷¹ Uu* (229)		⁷² Uu* (230)									
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																				⁶⁹ Uu* (227)		⁷⁰ Uu* (228)									
																				⁶⁸ Uu* (226)		⁶⁹ Uu* (227)									
																				⁶⁷ Uu* (225)		⁶⁸ Uu* (226)									
																				⁶⁶ Uu* (224)		⁶⁷ Uu* (225)									
																				⁶⁵ Uu* (223)		⁶⁶ Uu* (224)									
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																				⁶¹ Uu* (219)		⁶² Uu* (220)									
																				⁶⁰ Uu* (218)		⁶¹ Uu* (219)									
																				⁵⁹ Uu* (217)		⁶⁰ Uu* (218)									
																				⁵⁸ Uu* (216)		⁵⁹ Uu* (217)									
																				⁵⁷ Uu* (215)		⁵⁸ Uu* (216)									
																				⁵⁶ Uu* (214)		⁵⁷ Uu* (215)									
																				⁵⁵ Uu* (213)		⁵⁶ Uu* (214)									
																				⁵⁴ Uu* (212)		⁵⁵ Uu* (213)									
																				⁵³ Uu* (211)		⁵⁴ Uu* (212)									
																				⁵² Uu* (210)		⁵³ Uu* (211)									
																				⁵¹ Uu* (209)		⁵² Uu* (210)									
																				⁵⁰ Uu* (208)		⁵¹ Uu* (209)									
																				⁴⁹ Uu* (207)		⁵⁰ Uu* (208)									
																				⁴⁸ Uu* (206)		⁴⁹ Uu* (207)									
																				⁴⁷ Uu* (205)		⁴⁸ Uu* (206)									
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																				³⁶ Uu* (194)		³⁷ Uu* (195)									
																				³⁵ Uu* (193)		³⁶ Uu* (194)									
																				³⁴ Uu* (192)		³⁵ Uu* (193)									
																				³³ Uu* (191)		³⁴ Uu* (192)									
																				³² Uu* (190)		³³ Uu* (191)									
																				³¹ Uu* (189)		³² Uu* (190)									
																				³⁰ Uu* (188)		³¹ Uu* (189)									
																				²⁹ Uu* (187)		³⁰ Uu* (188)									
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																				²⁷ Uu* (185)		²⁸ Uu* (186)									
																				²⁶ Uu* (184)		²⁷ Uu* (185)									
																				²⁵ Uu* (183)		²⁶ Uu* (184)									
																				²⁴ Uu* (182)		²⁵ Uu* (183)									
																				²³ Uu* (181)		²⁴ Uu* (182)									
																				²² Uu* (180)		²³ Uu* (181)									

Type of absorption	Frequency, cm^{-1} (Intensity)*	Comment
Alkanes		
C—H stretch	2850–3000 (m)	occurs in all compounds with aliphatic C—H bonds
Alkenes		
C=C stretch —CH=CH ₂	1640 (m)	
	1655 (m)	
others	1660–1675 (w)	not observed if alkene is symmetrical
=C—H stretch	3000–3100 (m)	
=C—H bend		
—CH=CH ₂	910–990 (s)	
	890 (s)	
	960–980 (s)	
	675–730 (s)	position is highly variable
	800–840 (s)	
Alcohols and Phenols		
O—H stretch	3200–3400 (s)	
C—O stretch	1050–1250 (s)	also present in other compounds with C—O bonds: ethers, esters, etc.
Alkynes		
C≡C stretch	2100–2200 (m)	not present or weak in many internal alkynes
≡C—H stretch	3300 (s)	present in 1-alkynes only
Aromatic Compounds		
C=C stretch	1500, 1600 (s)	two absorptions
C—H bend	650–750 (s)	
overtone	1660–2000 (w)	

*(s) = strong; (m) = medium; (w) = weak.

(Table continues)

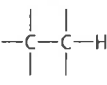


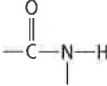

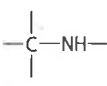

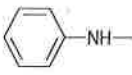

Type of absorption	Frequency, cm^{-1} (Intensity)*	Comment
Aldehydes		
C=O stretch ordinary	1720–1725 (s)	
α,β -unsaturated benzaldehydes	1680–1690 (s) 1700 (s)	
C—H stretch	2720 (m)	
Ketones		
C=O stretch ordinary	1710–1715 (s)	increases with decreasing ring size (Table 21.3, p. 996)
α,β -unsaturated aryl ketones	1670–1680 (s) 1680–1690 (s)	
Carboxylic Acids		
C=O stretch ordinary benzoic acids	1710 (s) 1680–1690 (s)	
O—H stretch	2400–3000 (s)	very broad
Esters and Lactones		
C=O stretch	1735–1745 (s)	increases with decreasing ring size (Table 21.3, p. 996)
Acid Chlorides		
C=O stretch	1800 (s)	a second weaker band sometimes observed at 1700–1750
Anhydrides		
C=O stretch	1760, 1820 (s)	two bands; increases with decreasing ring size in cyclic anhydrides
Amides and Lactams		
C=O stretch	1650–1655 (s)	increases with decreasing ring size (Table 21.3, p. 996)
N—H bend	1640 (s)	
N—H stretch	3200–3400 (m)	doublet absorption observed for some primary amides
Nitriles		
C \equiv N stretch	2200–2250 (m)	
Amines		
N—H stretch	3200–3375 (m)	several absorptions sometimes observed, especially for primary amines

* (s) = strong; (m) = medium; (w) = weak.

APPENDIX III. PROTON NMR CHEMICAL SHIFTS IN ORGANIC COMPOUNDS

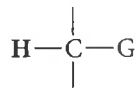
This appendix is subdivided into a table of chemical shifts for protons that are *part of* functional groups and a table of chemical shifts for protons that are *adjacent to* functional groups.

A. Protons within Functional Groups

Group	Chemical shift, ppm	Group	Chemical shift, ppm
	0.7-1.5		9-11
	4.6-5.7		7.5-9.5
	varies with solvent and with acidity of O—H		0.5-1.5
	1.7-2.5		2.5-3.5
	6.5-8.5		




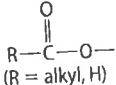
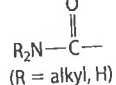
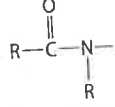
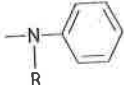
B. Protons Adjacent to Functional Groups

In this table, a range of chemical shifts is given for protons in the general environment



in which G is a group listed in column 1, and the two other bonds are to carbon or hydrogen. The remaining columns give the approximate chemical shifts for methyl protons ($\text{H}_3\text{C}-\text{G}$), methylene protons ($-\text{CH}_2-\text{G}$), and methine protons ($-\text{CH}-\text{G}$), respectively. The shifts in the following table are typical; some variation with structure of a few tenths of a ppm can be expected. The chemical shifts of methine protons are usually further downfield than those of methylene protons, which are further downfield than methyl protons. Each additional carbon substitution increases the chemical shift by 0.3-1.0 ppm.


A-6 APPENDICES

Group, G	Chemical shift of H ₃ C—G, ppm	Chemical shift of —CH ₂ —G, ppm	Chemical shift of —CH—G, ppm
—H	0.2		
—CR ₃	0.9	1.2	1.4
—F	4.3	4.5	4.8
—Cl	3.0	3.4	4.0
—Br	2.7	3.4	4.1
—I	2.2	3.2	4.2
—CR=CR ₂ (R = H, alkyl)	1.8	2.0	2.3
—C≡CR (R = alkyl, H)	1.8	2.2	2.8
	2.3	2.6	2.8
RO— (R = alkyl, H)	3.3 (R = alkyl) 3.5 (R = H)	3.4	3.6
RO— (R = aryl)	3.7	4.0	4.6
RS— (R = alkyl, H)	2.4	2.6	3.0
	2.1 (R = alkyl) 2.6 (R = aryl)	2.4 (R = alkyl) 2.7 (R = aryl)	2.6 (R = alkyl) 3.4 (R = aryl)
 (R = alkyl, H)	2.1	2.2	2.5
 (R = alkyl, H)	3.6 (R = alkyl) 3.8 (R = aryl)	4.1 (R = alkyl, aryl)	5.0 (R = alkyl, aryl)
 (R = alkyl, H)	2.0	2.2	2.4
 (R = alkyl, H)	2.8	3.4	3.8
—NR ₂ (R = alkyl, H)	2.2	2.4	2.8
 (R = alkyl, H)	2.6	3.1	3.6
N≡C—	2.0	2.4	2.9

APPENDIX IV. ^{13}C NMR CHEMICAL SHIFTS IN ORGANIC COMPOUNDS

This section is divided into a table of chemical shifts for carbons within functional groups and a table of chemical shifts for alkyl carbons adjacent to functional groups. A typical range of shifts is given for each case.

A. Chemical Shifts of Carbons within Functional Groups




Group	Chemical shift range, ppm
$-\text{CH}_3$	8–23
$-\text{CH}_2-$	20–30
$-\overset{ }{\text{C}}\text{H}-$	21–33
$-\overset{ }{\underset{ }{\text{C}}}-$	17–29
$\begin{array}{c} \diagup \quad \diagdown \\ \text{C}=\text{C} \\ \diagdown \quad \diagup \end{array}$	105–150*
$-\text{C}\equiv\text{C}-$	66–93*
	125–150*
$\begin{array}{c} \text{O} \\ \\ \text{C} \\ \diagup \quad \diagdown \end{array}$	200–220
$\begin{array}{c} \text{O} \\ \\ \text{C} \\ \diagup \quad \diagdown \\ \quad \quad \quad \text{O}-\text{R} \end{array}$ R = H, alkyl	170–180
$\begin{array}{c} \text{O} \\ \\ \text{C} \\ \diagup \quad \diagdown \\ \quad \quad \quad \text{N}-\text{R} \\ \quad \quad \quad \\ \quad \quad \quad \text{R} \end{array}$ R = H, alkyl	165–175
$-\text{C}\equiv\text{N}$	110–120

*Alkyl substitution typically increases chemical shift.

B. Chemical Shifts of Carbons Adjacent to Functional Groups

In most cases, alkyl substitution on the carbon increases chemical shift. Methyl carbons will have shifts in the low end of the range; tertiary and quaternary carbons will have shifts in the upper end of the range.

A-8 APPENDICES

Group G	Chemical shift of carbon in G—C—
$R_2C=CR-$	14-40
$HC\equiv C-$	18-28
	29-45
F—	83-91
Cl—	44-68
Br—	32-65
I—	5-42
HO—	62-70
RO— R = alkyl, H	70-79
 R = alkyl, H	43-50
 R = alkyl, H	33-44
R_2N- R = alkyl, H	41-51 (R = H) 53-60 (R = alkyl)
$N\equiv C-$	16-28