

DIAGNOSIS OF FUNCTIONAL GROUPS IN ORGANIC COMPOUNDS

Dr. Nagham Mahmood Aljamali

Organic Chemistry , Chemistry Department , College of Education .

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ABSTRACT

There are general methods that can be used for the determination of a molecular structure of any compound (organic and inorganic) like Spectroscopic techniques of reactions , reagents , through physical properties , solubility and other methods

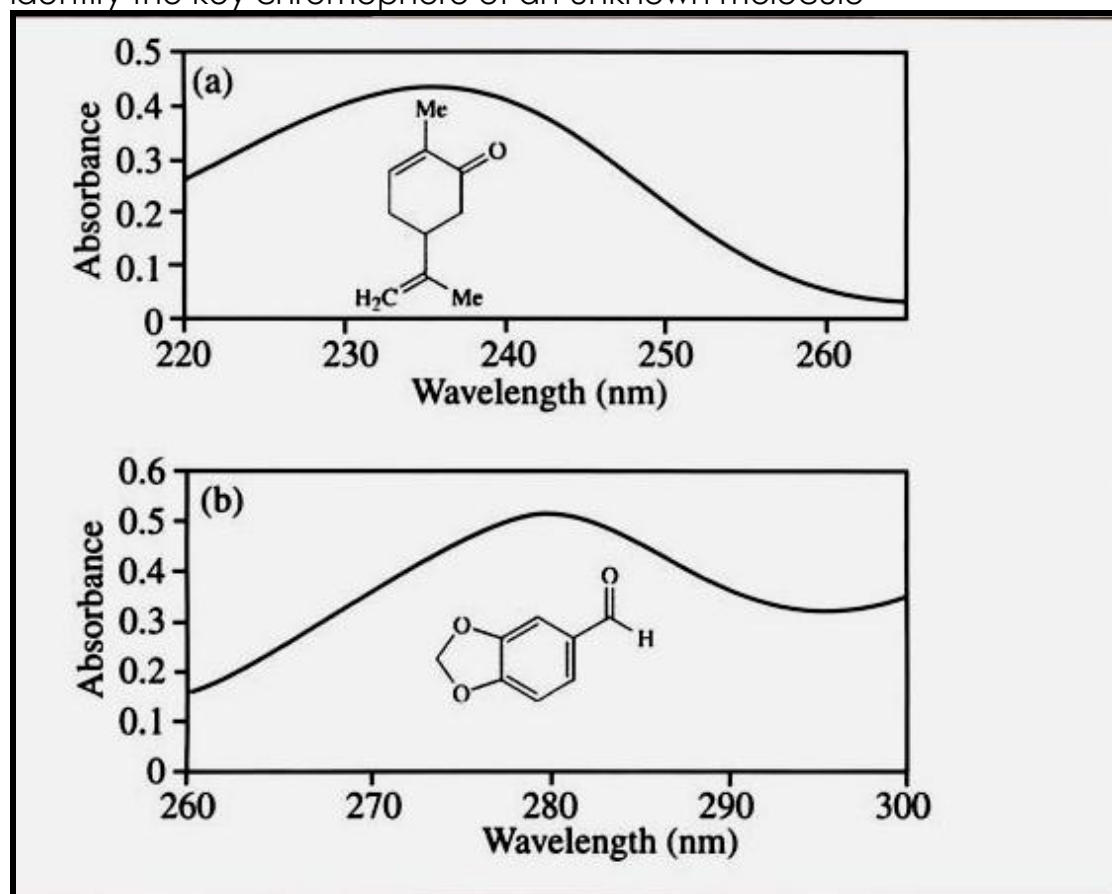
Keywords: distinguish , identification , spectra , reaction, reagent , determination , mass , H.NMR , C.NMR , I.R .

No: of References: 14



Introduction

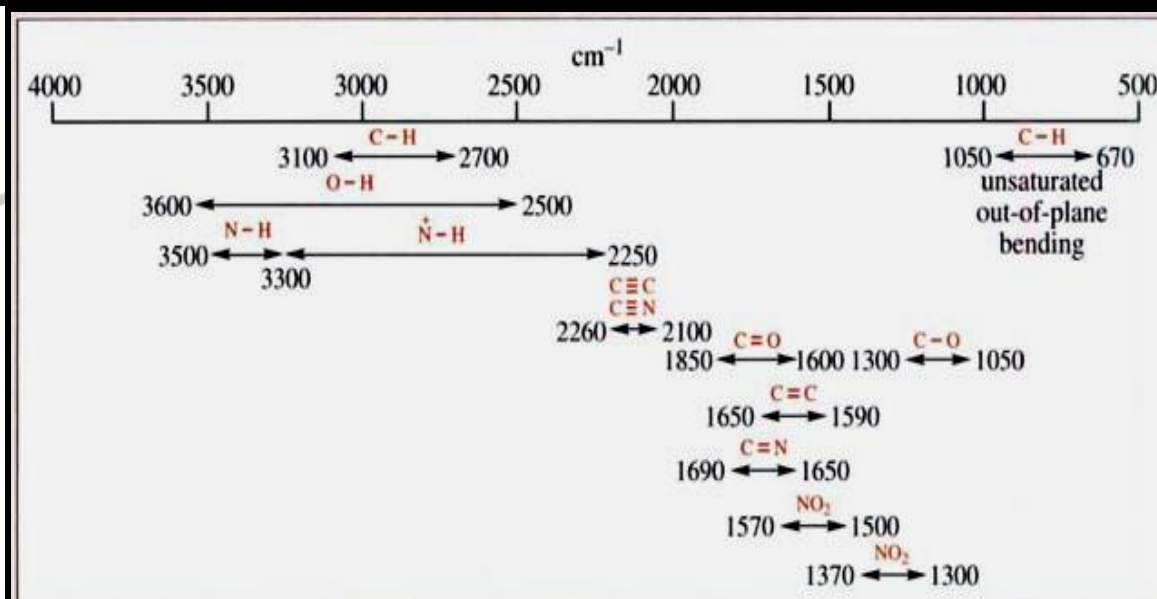
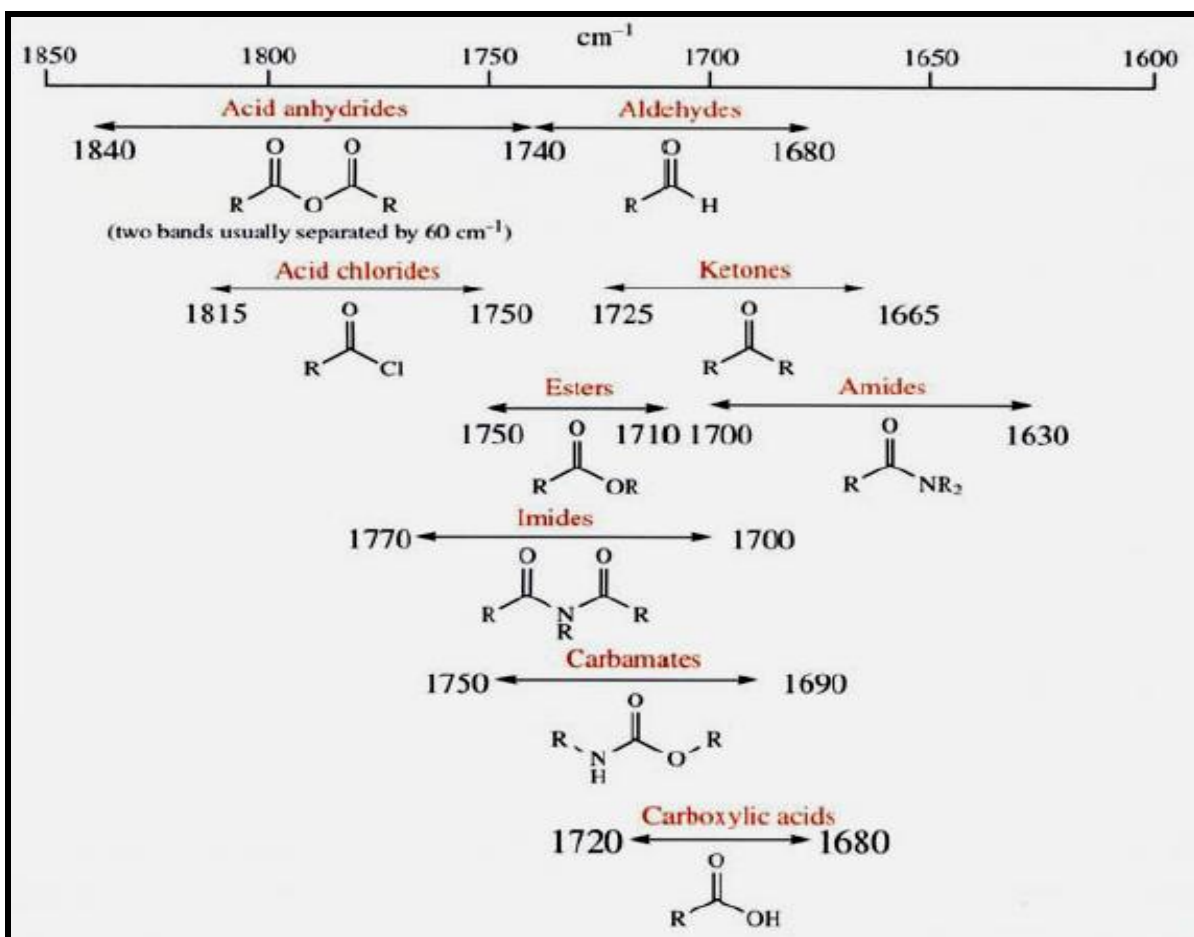
Before NMR spectroscopy and mass spectrometry revolutionized the structural elucidation of organic molecules, UV spectroscopy was an important technique and was used to identify the key chromophore of an unknown molecule

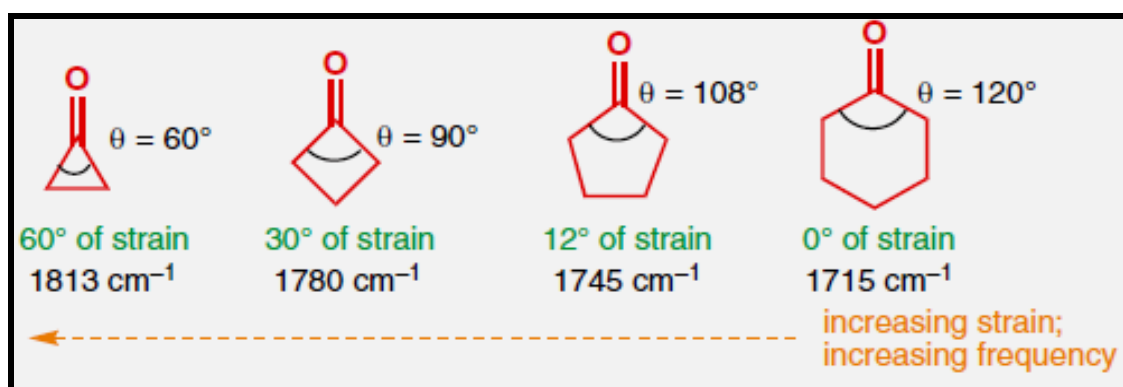
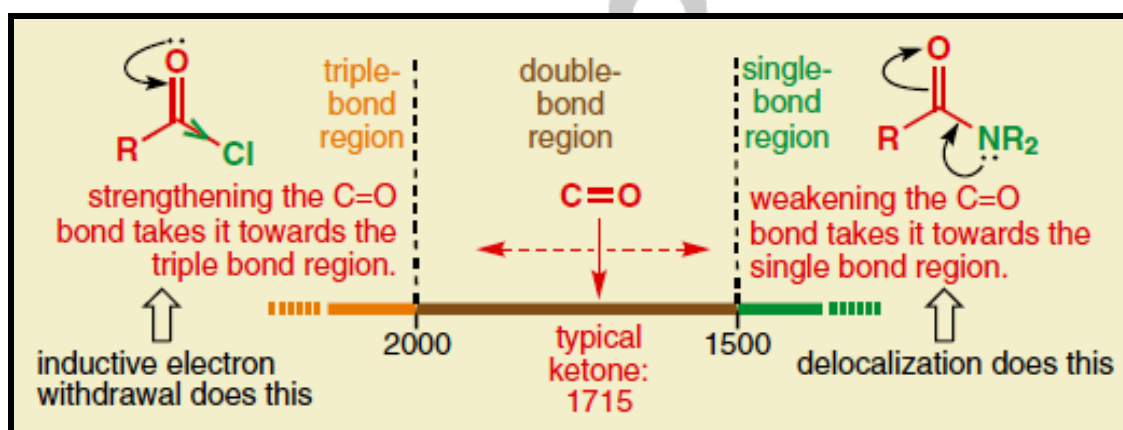
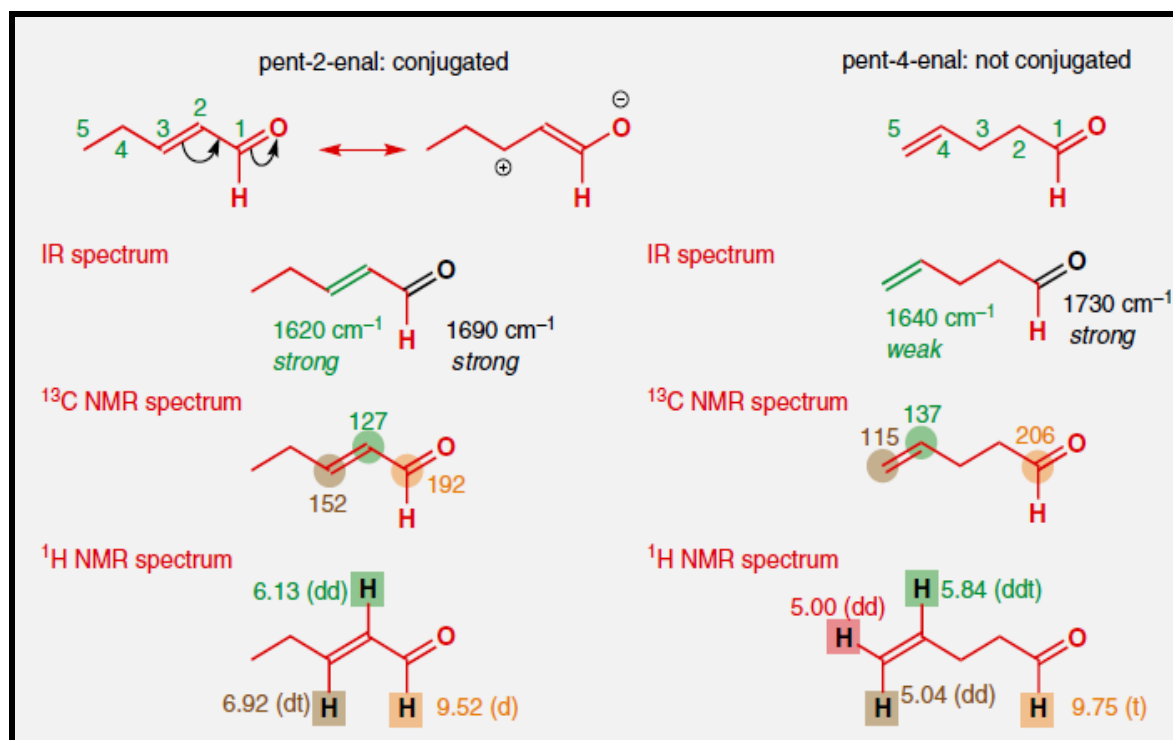


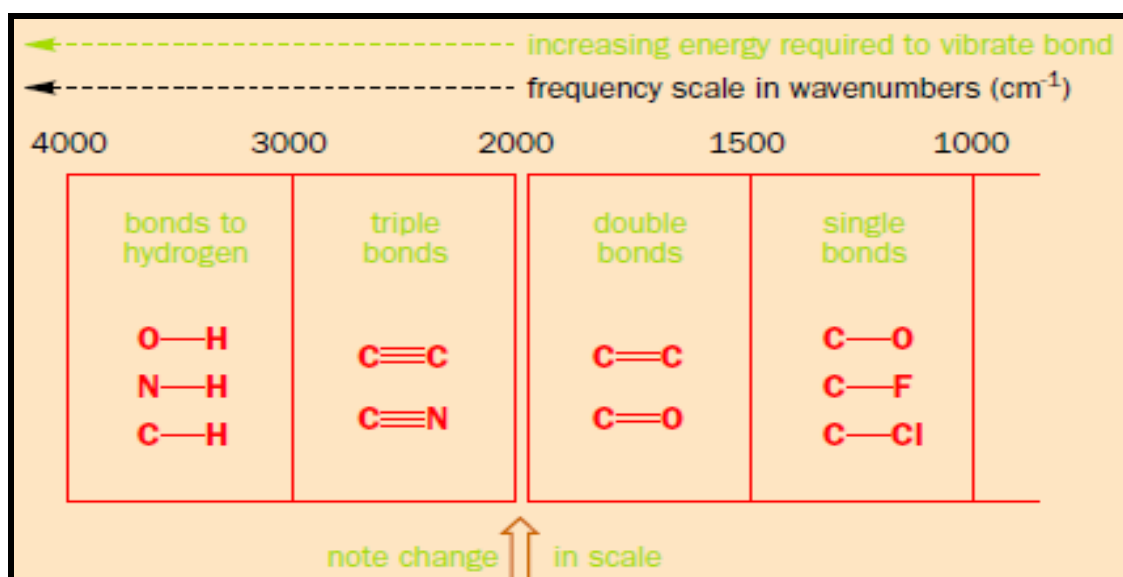
Hydrogen bonding also leads to a decrease in the carbonyl stretching frequency, since we can think of the hydrogen bond as utilizing some of the carbonyl bond electron density. This results in a lower bond order for this bond, and a consequently lower stretching frequency. One interesting aspect of the effect of hydrogen bonding on the IR spectrum of carbonyl compounds is the effect of intra- and intermolecular hydrogen bonding. **Intramolecular hydrogen bonding** (within one molecule) is *independent of the concentration* of the sample and so the position of the carbonyl band will not vary with concentration. **Intermolecular hydrogen bonding**, the other hand, is *dependent upon the concentration*, since the more concentrated the sample, the greater the extent of the hydrogen bonding, and so the position of the carbonyl band will vary with concentration. The more concentrated the sample, the lower the stretching frequency.

<i>Functional group</i>	<i>Stretching vibration/cm⁻¹</i>
-C≡C- (alkynes)	Terminal R-C≡C-H Internal R-C≡C-R
-C≡N (nitriles)	2260-2100
-N ⁺ ≡N (diazonium salts)	2280-2240
-N=N ⁺ =N ⁻ (azides)	2160-2100
-C ⁺ =N=N ⁻ (dialzo compounds)	2050-2000
-N=C=N- (carbodiimides)	2150-2110
-C=C=C- (allenes)	~1950
C=C=O (ketenes)	~2150
CO ₂	2350







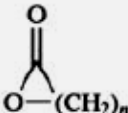
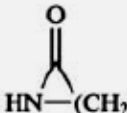


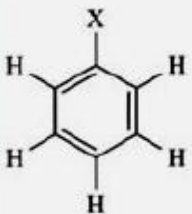
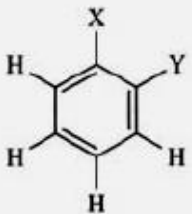
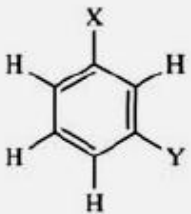
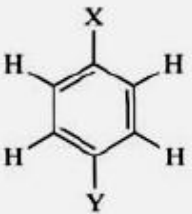
Useful absorptions in the fingerprint region

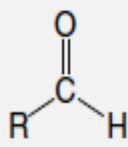
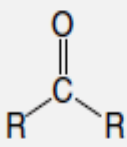
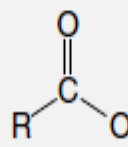
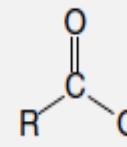
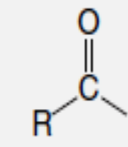
Frequency, cm^{-1}	Strength	Group	Comments
1440–1470	medium	CH ₂	deformation (present in nujol)
~1380	medium	CH ₃	deformation (present in nujol)
~1350	strong	NO ₂	symmetrical N=O stretch
1250–1300	strong	P=O	double bond stretch
1310–1350	strong	SO ₂	antisymmetrical S=O stretch
1120–1160	strong	SO ₂	symmetrical S=O stretch
~1100	strong	C–O	single bond stretch
950–1000	strong	C=CH	<i>trans</i> alkene (out-of-plane deformation)
~690 and ~750	strong	Ar–H	five adjacent Ar–H (out-of-plane)
~750	strong	Ar–H	four adjacent Ar–H (out-of-plane)
~700	strong	C–Cl	single bond stretch

Effects of substituents on IR carbonyl frequencies		
Effect	Group	C=O stretch, cm^{-1}
inductive effect	Cl	1800
	OCOR	1765, 1815
	OR	1745
	H	1730
conjugation	C=C	1685
	aryl	1685
	NH ₂	1630
ring strain	five-membered ring	1745
	four-membered ring	1780
	three-membered ring	1815

Effect of Strain :

<i>Lactones</i>	<i>Lactams (dilute solutions)</i>
 $\text{O}-(\text{CH}_2)_n$	 $\text{HN}-(\text{CH}_2)_n$
$n=2$; 1840 cm^{-1}	$n=2$; 1750 cm^{-1}
$n=3$; 1770 cm^{-1}	$n=3$; 1700 cm^{-1}
$n=4$; 1740 cm^{-1}	$n=4$; 1660 cm^{-1}
Saturated acyclic ester: $\sim 1740 \text{ cm}^{-1}$	Saturated acyclic amide: $\sim 1660 \text{ cm}^{-1}$

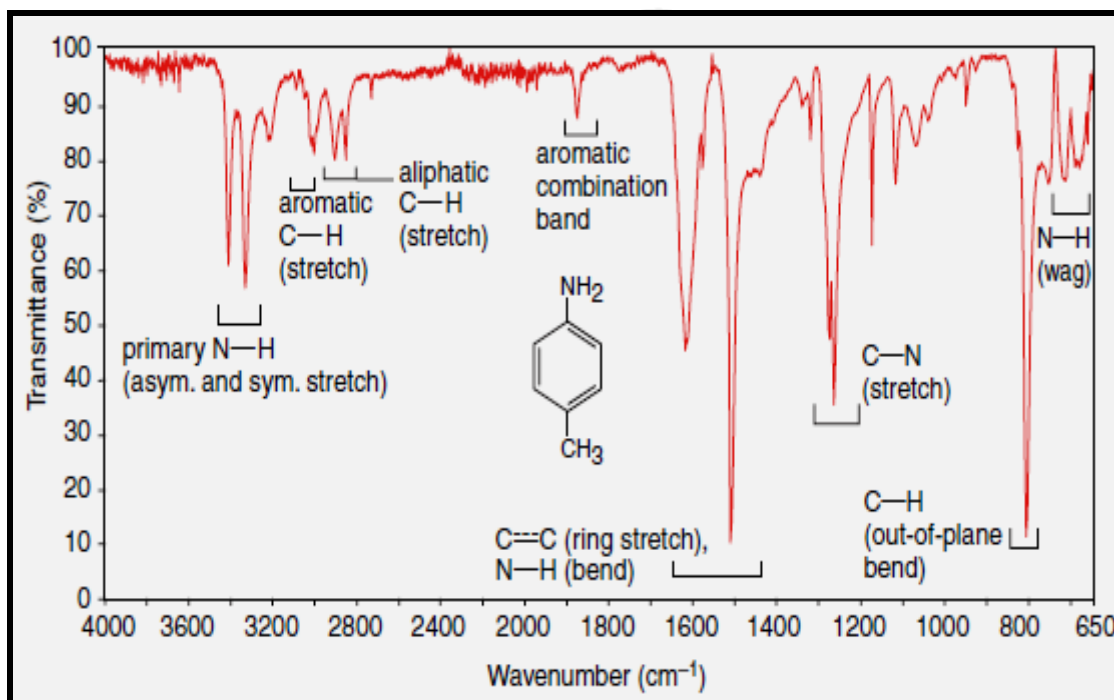
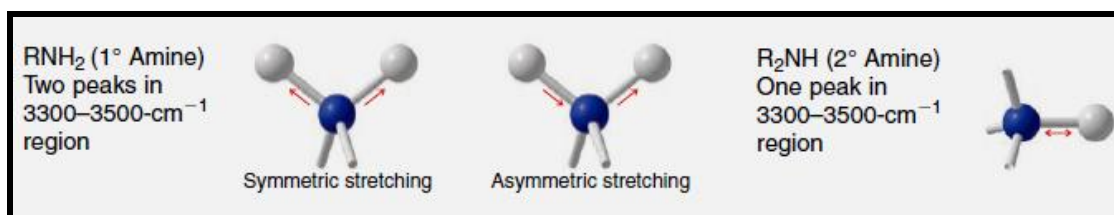
Aromatic Rings			
<i>Monosubstituted</i>	<i>1,2-Disubstituted (ortho)</i>	<i>1,3-Disubstituted (meta)</i>	<i>1,4-Disubstituted (para)</i>
			
770–730 (740) cm^{-1} 710–690 (690) cm^{-1}	770–735 cm^{-1}	810–750 cm^{-1} 725–680 cm^{-1}	860–800 cm^{-1}

				
Aldehyde 1690–1740 cm^{-1}	Ketone 1680–1750 cm^{-1}	Ester 1735–1750 cm^{-1}	Carboxylic acid 1710–1780 cm^{-1}	Amide 1630–1690 cm^{-1}

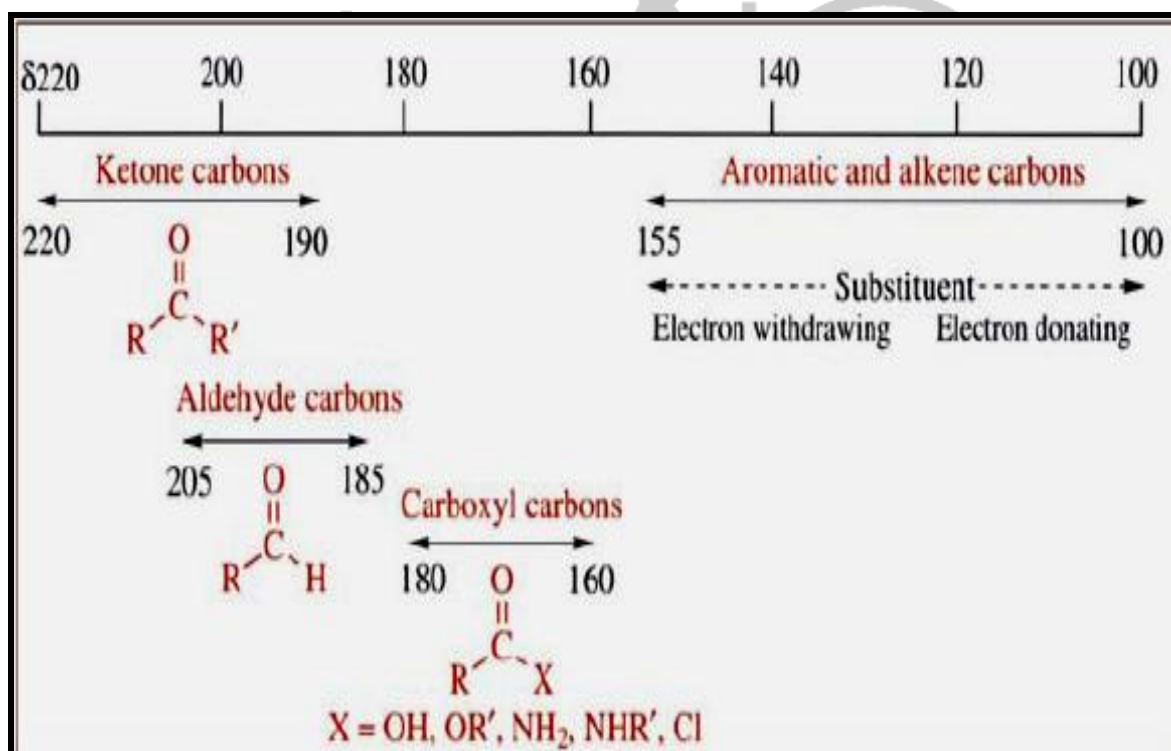
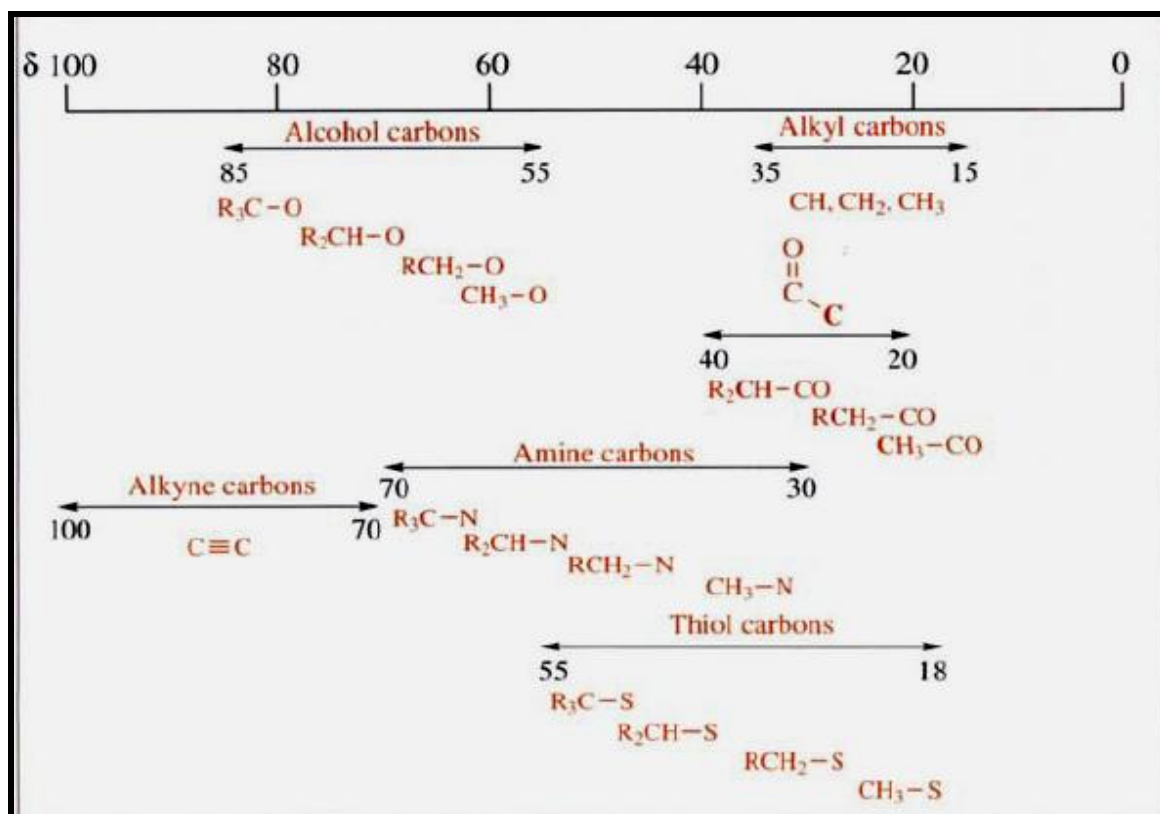
GROUP	BOND	FREQUENCY RANGE (cm^{-1})
Alkyl	C—H	2853–2962
Alcohol	O—H	3590–3650
Amine	N—H	3300–3500

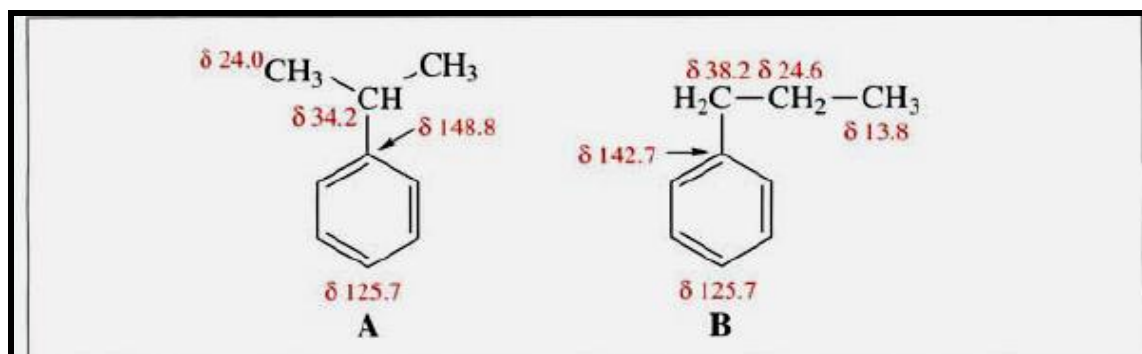
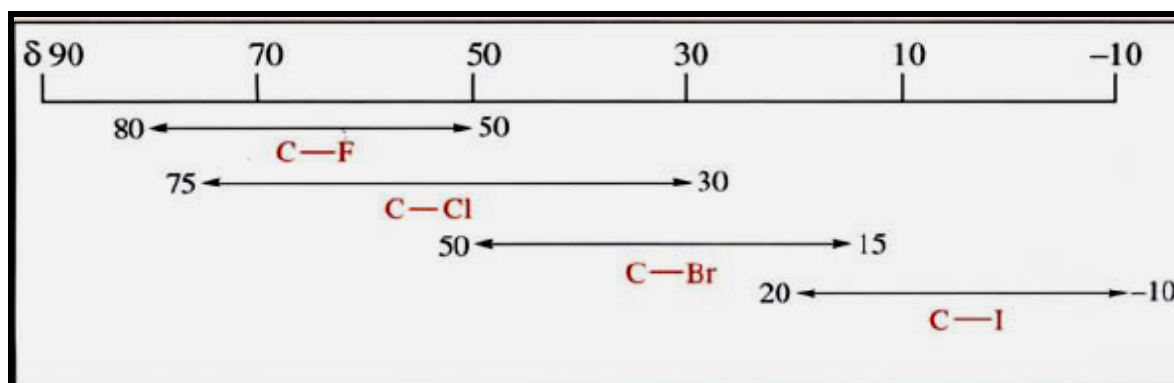
BOND	FREQUENCY RANGE (cm^{-1})
C≡C	2100–2260
C≡N	2220–2260
C=C	1620–1680
C=O	1630–1780

- Primary (1°) and secondary (2°) amines give absorptions of moderate strength in the $3300\text{--}3500\text{-cm}^{-1}$ region.
- Primary amines exhibit two peaks in this region due to symmetric and asymmetric stretching of the two N—H bonds.
- Secondary amines exhibit a single peak.
- Tertiary amines show no N—H absorption because they have no such bond.
- A basic pH is evidence for any class of amines.



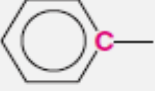
Diagnosis via $^{13}\text{C.NMR}$ - Chemical Shift :

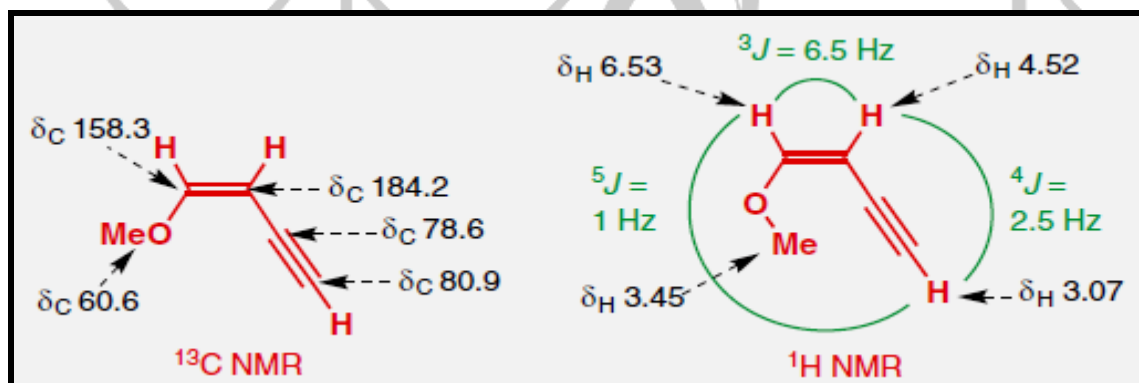




δ_C for alkylation products: assignment of the CH signals at δ 126.4 and 128.3 in **A** and 128.3 and 128.5 in **B** would require the use of HMBC spectra.

Approximate Carbon-13 Chemical Shifts

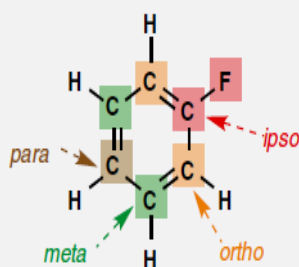
Type of Carbon Atom	Chemical Shift (δ , ppm)
1° Alkyl, RCH ₃	0–40
2° Alkyl, RCH ₂ R	10–50
3° Alkyl, RCHR ₂	15–50
Alkyl halide or amine, $\begin{array}{c} \\ -C-X \\ \end{array}$ (X= Cl, Br, or N—)	10–65
Alcohol or ether, $\begin{array}{c} \\ -C-O- \\ \end{array}$	50–90
Alkyne, $-C\equiv$	60–90
Alkene, $\begin{array}{c} \diagup \\ C= \\ \diagdown \end{array}$	100–170
Aryl, 	100–170
Nitrile, $-C\equiv N$	120–130
Amide, $\begin{array}{c} O \\ \\ -C-N- \\ \end{array}$	150–180
Carboxylic acid or ester, $\begin{array}{c} O \\ \\ -C-O- \\ \end{array}$	160–185
Aldehyde or ketone, $\begin{array}{c} O \\ \\ -C- \\ \end{array}$	182–215



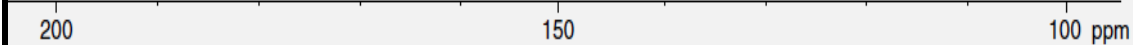
Coupling in carbon NMR spectra

We shall use coupling with fluorine to introduce this section. Fluorobenzenes are good examples because they have a number of different carbon atoms all coupled to the fluorine atom.

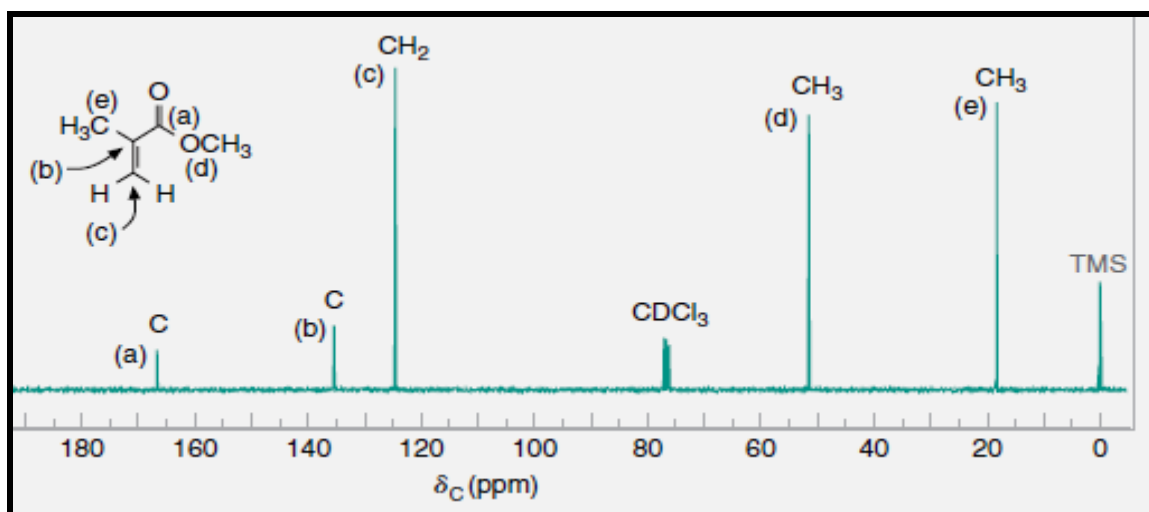
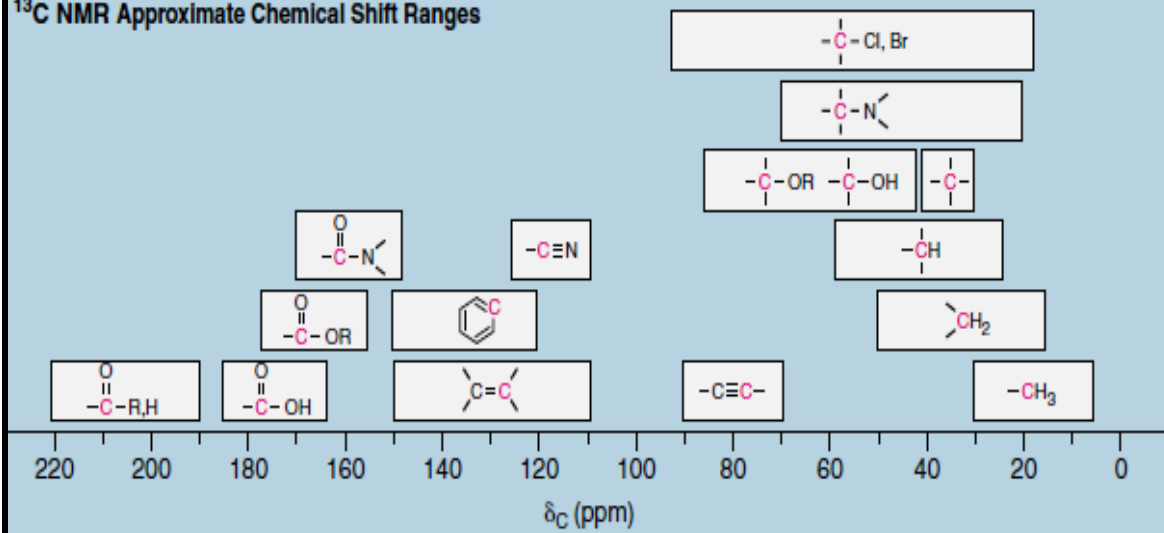
- 162.9 (d, $^1J_{FC}$ 244 Hz, ipso-C)
- 115.3 (d, $^2J_{FC}$ 21 Hz, ortho-C)
- 122.9 (d, $^3J_{FC}$ 7.5 Hz, meta-C)
- 123.9 (d, $^4J_{FC}$ 2Hz, para-C)

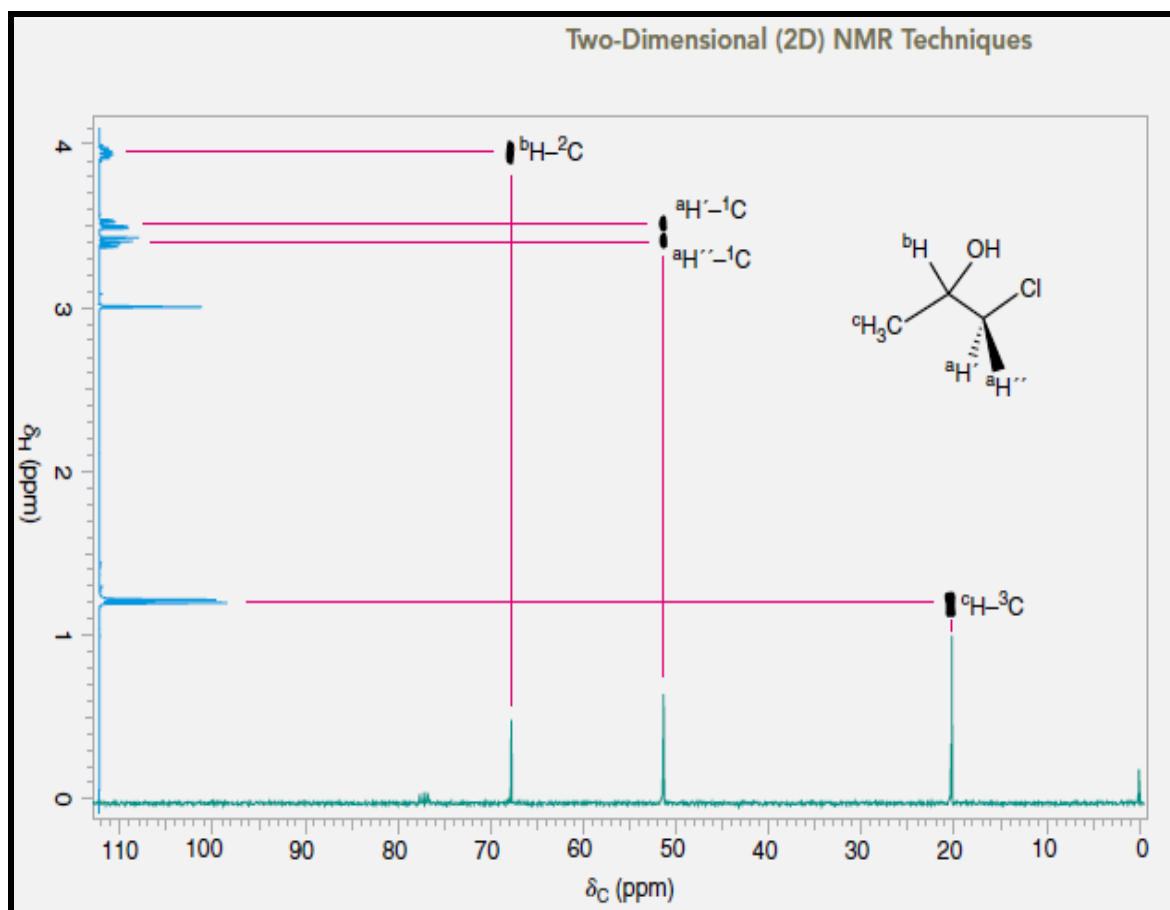


^{13}C NMR spectrum
50 MHz






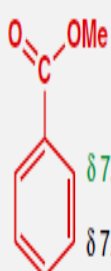


^{13}C NMR Approximate Chemical Shift Ranges





Diagnosis via ^1H -NMR – Spectra :

Nitro is just one of a number of groups that are also deactivating towards electrophiles and *meta* directing because of electron withdrawal by conjugation. Others include carbonyl groups (aldehydes, ketones, esters, etc.), nitriles, and sulfonates. The ^1H NMR shifts of rings carrying these substituents confirm that they remove electrons principally from the *ortho* and *para* positions.

^1H NMR chemical shifts	nitrobenzene	benzaldehyde	methyl benzoate	methyl benzenesulfonate	benzonitrile
					
δ 7.26	δ 8.21 δ 7.52 δ 7.64	δ 7.82 δ 7.48 δ 7.55	δ 7.97 δ 7.37 δ 7.47	δ 7.86 δ 7.52 δ 7.59	δ 7.62 δ 7.44 δ 7.54

PPM and the δ Scale

The chemical shift of a proton, when expressed in **hertz (Hz)**, is proportional to the strength of the external magnetic field. Since spectrometers with different magnetic field strengths are commonly used, it is desirable to express chemical shifts in a form that is independent of the strength of the external field. This can be done easily by dividing the chemical shift by the frequency of the spectrometer, with both numerator and denominator of the fraction expressed in frequency units (hertz). Since chemical shifts are always very small (typically <5000 Hz) compared with the total field strength (commonly the equivalent of 60, 300, or 600 million hertz), it is convenient to express these fractions in units of *parts per million* (ppm). This is the origin of the delta scale for the expression of chemical shifts relative to TMS:

$$\delta = \frac{(\text{observed shift from TMS in hertz}) \times 10^6}{(\text{operating frequency of the instrument in hertz})}$$

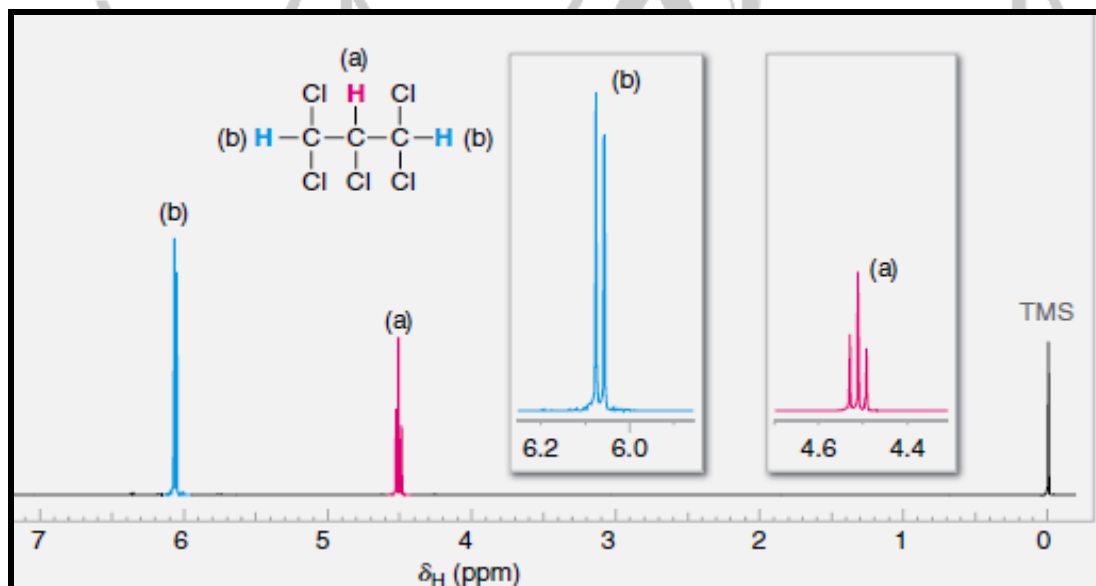
For example, the chemical shift for benzene protons is 2181 Hz when the instrument is operating at 300 MHz. Therefore,

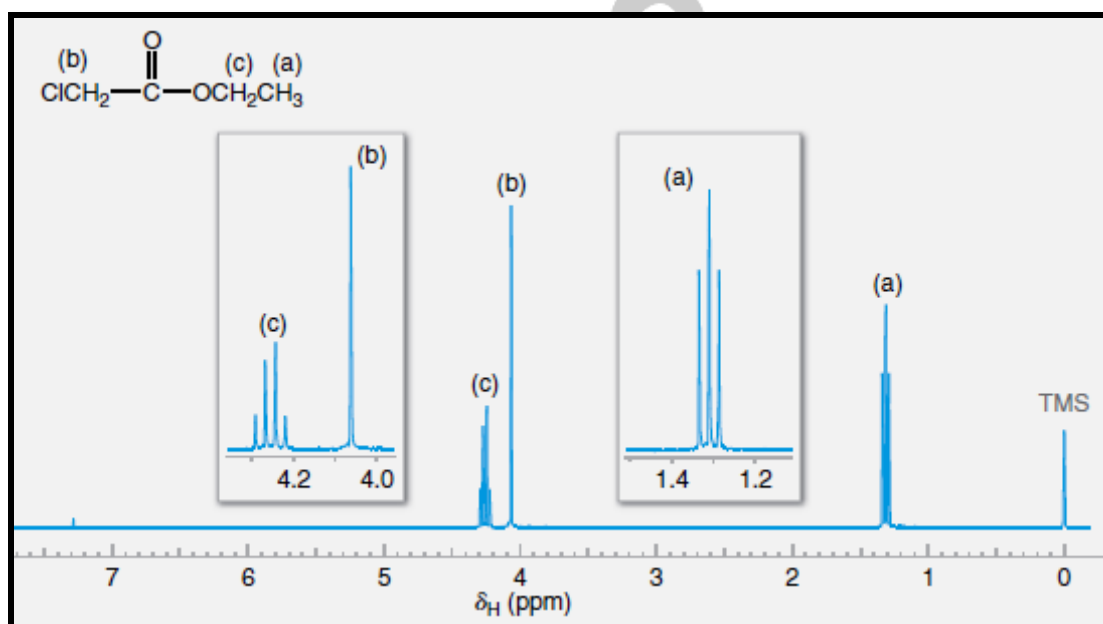
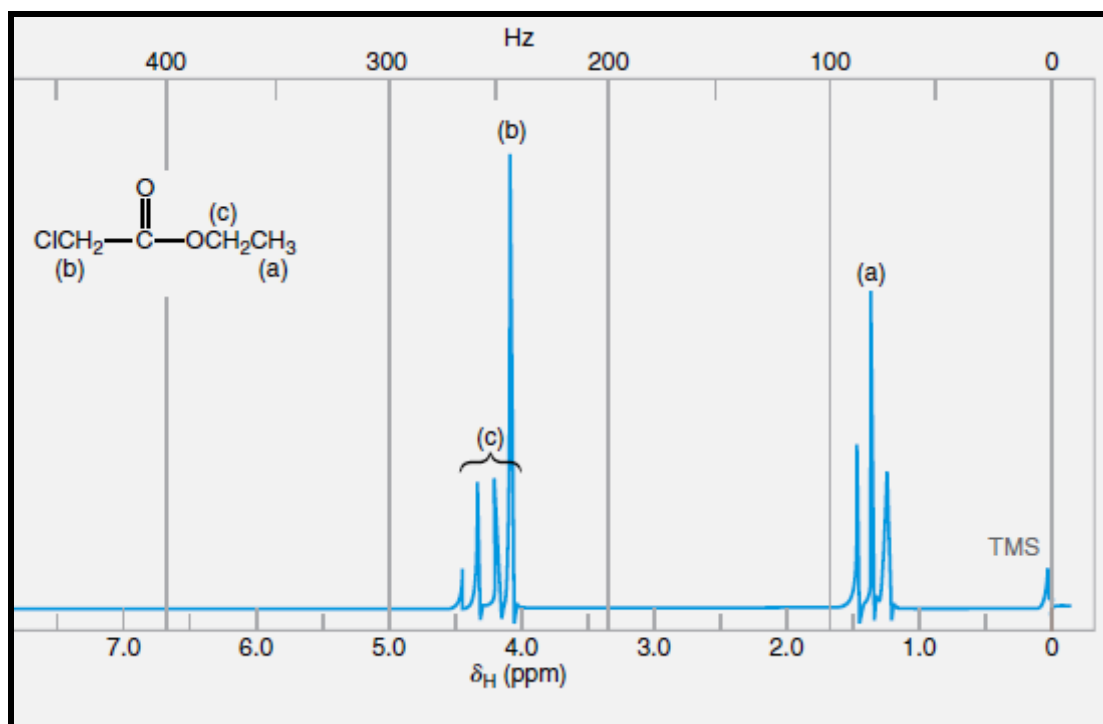
$$\delta = \frac{2181 \text{ Hz} \times 10^6}{300 \times 10^6 \text{ Hz}} = 7.27$$

The chemical shift of benzene protons in a 60-MHz instrument is 436 Hz:

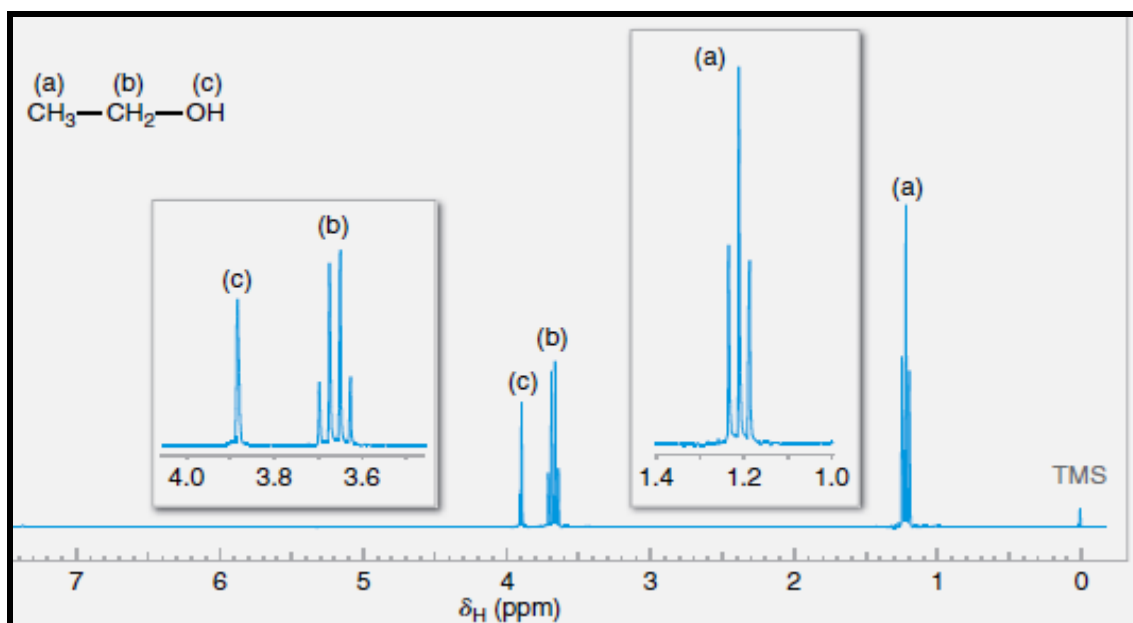
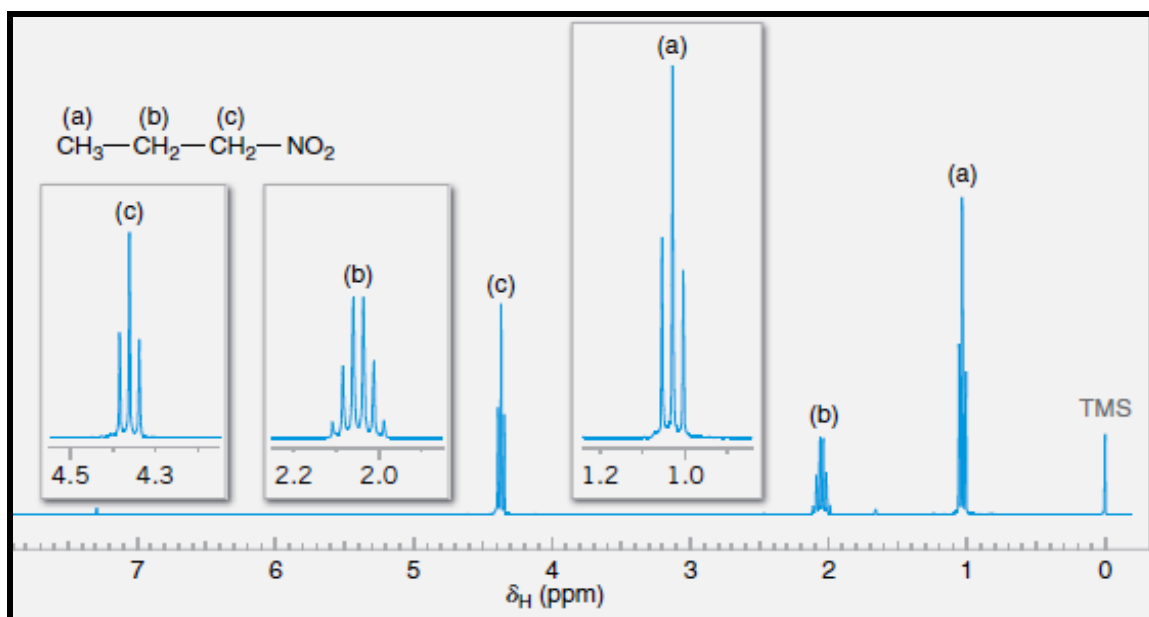
$$\delta = \frac{436 \text{ Hz} \times 10^6}{60 \times 10^6 \text{ Hz}} = 7.27$$

Thus, the chemical shift expressed in ppm is the same whether measured with an instrument operating at 300 or 60 MHz (or any other field strength).





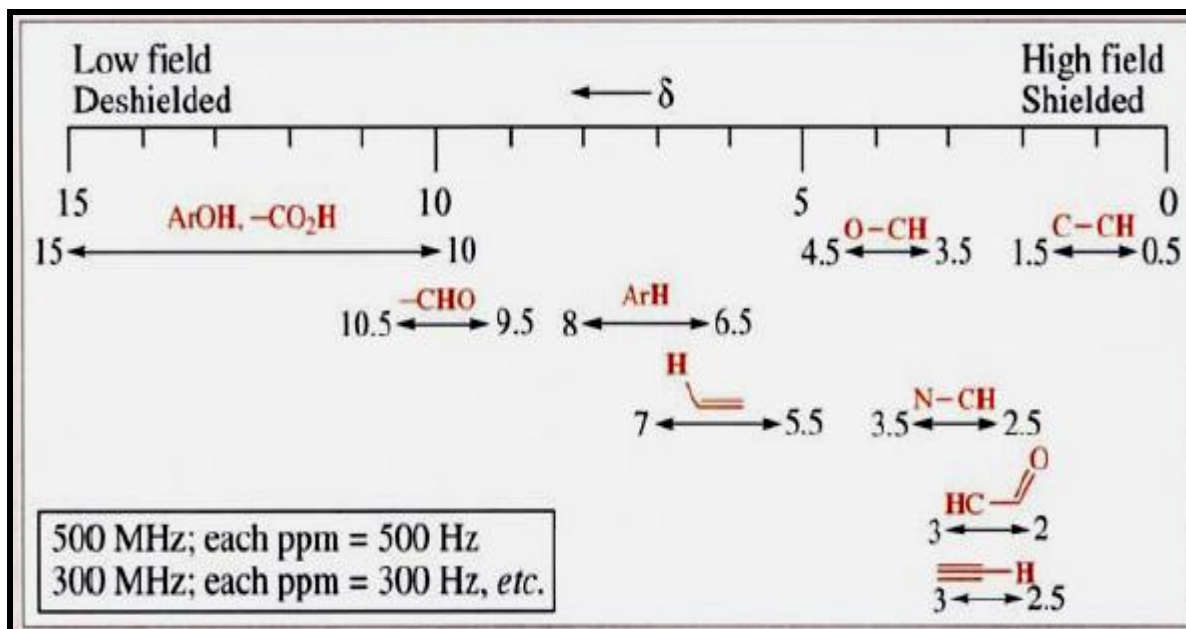
(Top) The 60-MHz ^1H NMR spectrum of ethyl chloroacetate. Note the overlapping signals at δ 4. (Bottom) The 300-MHz ^1H NMR spectrum of ethyl chloroacetate, showing resolution at higher magnetic field strength of the signals that overlapped at 60 MHz. Expansions of the signals are shown in the offset plots.

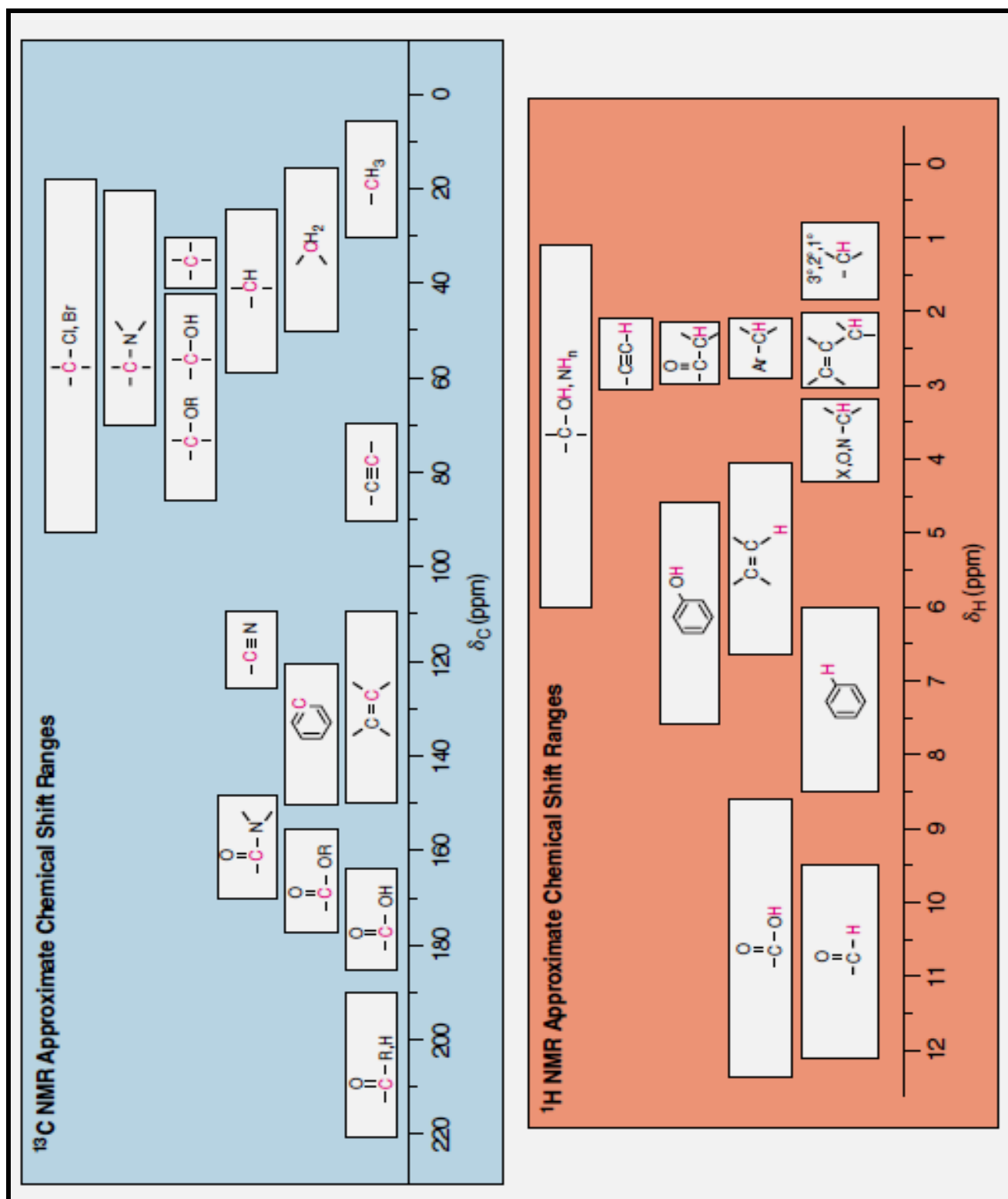


Chemical Shift For Solvents In [^1H , ^{13}C] – NMR] – Spectra :

Solvent	δ_H	δ_C
$CDCl_3$	7.25 (singlet)	77.0 (triplet)
$DMSO-d_6$ (CD_3SOCD_3)	2.50 (quintet)	40.4 (septet)
Acetone- d_6 (CD_3COCD_3)	2.05 (quintet)	30.5 (septet), 205.4 (singlet)
Acetonitrile- d_3 (CD_3CN)	1.95 (quintet)	1.2 (septet), 118.0 (singlet)
Methanol- d_4 (CD_3OD)	3.35 (quintet), 4.80 (singlet)	49.0 (septet)
D_2O	4.70 (singlet)	–

H.NMR - Chemical Shift :





Diagnosis via Mass Spectra :

Mass Spectrometry

For three of the elements—carbon, hydrogen, and nitrogen—the principal heavier isotope is one mass unit greater than the most common isotope.

- The presence of isotopes of carbon, hydrogen, and nitrogen in a compound gives rise to a small $M^+ + 1$ peak.

For four of the elements—oxygen, sulfur, chlorine, and bromine—the principal heavier isotope is two mass units greater than the most common isotope.

- The presence of oxygen, sulfur, chlorine, or bromine in a compound gives rise to an $M^+ + 2$ peak.

$M^+ + 1$ Elements: C, H, N

$M^+ + 2$ Elements: O, S, Br, Cl

- The $M^+ + 1$ peak can be used to determine the number of carbons in a molecule.
- The $M^+ + 2$ peak can indicate whether bromine or chlorine is present.
- The isotopic peaks, in general, give us one method for determining molecular formulas.

To understand how we can determine the number of carbons, let us begin by noticing that the isotope abundances in Table 9.4 are based on 100 atoms of the normal isotope. Now let us suppose, as an example, that we have 100 molecules of methane (CH_4). On the average there will be 1.11 molecules that contain a ^{13}C atom and 4×0.016 molecules that contain a ^2H atom. Altogether, then, these heavier isotopes should contribute an $M^+ + 1$ peak whose intensity is about 1.17% of the intensity of the peak for the molecular ion:

$$1.11 + 4(0.016) \cong 1.17\%$$



How to Determine the Molecular Formula

For molecules with a modest number of atoms we can determine molecular formulas in the following way. If the M^+ peak is not the base peak, the first thing we do with the mass spectrum of an unknown compound is to recalculate the intensities of the $M^+ + 1$ and $M^+ + 2$ peaks to express them as percentages of the intensity of the M^+ peak.

Consider, for example, the mass spectrum of an unknown compound given in Fig. 9.43. The M^+ peak at m/z 72 is not the base peak. Therefore, we need to recalculate the intensities of the peaks in our spectrum at m/z 72, 73, and 74 as percentages of the peak at m/z 72. We do this by dividing each intensity by the intensity of the M^+ peak, which is 73%, and multiplying by 100. These results are shown here and in the second column of Fig. 9.43.

m/z	Intensity (% of M^+)
72	$73.0/73 \times 100 = 100$
73	$3.3/73 \times 100 = 4.5$
74	$0.2/73 \times 100 = 0.3$

Then we use the following guides to determine the molecular formula:

1. Is M^+ odd or even? According to the **nitrogen rule**, if it is even, then the compound must contain an even number of nitrogen atoms (zero is an even number). For our unknown, M^+ is even. The compound must have an even number of nitrogen atoms.

Example :

m/z	Intensity (as percent of base peak)	m/z	Intensity (as percent of M^+)
27	59.0	72	M^+ 100.0
28	15.0	73	$M^+ + 1$ 4.5
29	54.0	74	$M^+ + 2$ 0.3
39	23.0		
41	60.0		
42	12.0		
43	79.0		
44	100.0 (base)		
72	73.0 M^+		
73	3.3		
74	0.2		

Recalculated to base on M^+

2. The relative abundance of the $M^{\dagger} + 1$ peak indicates the number of carbon atoms. Number of C atoms = relative abundance of $(M^{\dagger} + 1)/1.1$. For our unknown (Fig. 9.43),

$$\text{Number of C atoms} = \frac{4.5}{1.1} \cong 4$$

(This formula works because ^{13}C is the most important contributor to the $M^{\dagger} + 1$ peak and the approximate natural abundance of ^{13}C is 1.1%.)

3. The relative abundance of the $M^{\dagger} + 2$ peak indicates the presence (or absence) of S (4.4%), Cl (33%), or Br (98%) (see Table 9.4). For our unknown, $M^{\dagger} + 2 = 0.3\%$; thus, we can assume that S, Cl, and Br are absent.
4. The molecular formula can now be established by determining the number of hydrogen atoms and adding the appropriate number of oxygen atoms, if necessary.

For our unknown the M^{\dagger} peak at m/z 72 gives us the molecular weight. It also tells us (since it is even) that nitrogen is absent because a compound with four carbons (as established above) and two nitrogens (to get an even molecular weight) would have a molecular weight (76) greater than that of our compound.

For a molecule composed of C and H only,

$$\text{H} = 72 - (4 \times 12) = 24$$

but C_4H_{24} is impossible.

For a molecule composed of C, H, and one O,

$$\text{H} = 72 - (4 \times 12) - 16 = 8$$

and thus our unknown has the molecular formula $\text{C}_4\text{H}_8\text{O}$.

Solved Problem

- (a) What approximate intensities would you expect for the M^{\dagger} and $M^{\dagger} + 2$ peaks of CH_3Cl ?
- (b) For the M^{\dagger} and $M^{\dagger} + 2$ peaks of CH_3Br ?
- (c) An organic compound gives an M^{\dagger} peak at m/z 122 and a peak of nearly equal intensity at m/z 124. What is a likely molecular formula for the compound?

STRATEGY AND ANSWER

- (a) The $M^{\dagger} + 2$ peak due to $\text{CH}_3\text{—}^{37}\text{Cl}$ (at m/z 52) should be almost one-third (32.5%) as large as the M^{\dagger} peak at m/z 50 because of the relative natural abundances of ^{35}Cl and ^{37}Cl .
- (b) The peaks due to $\text{CH}_3\text{—}^{79}\text{Br}$ and $\text{CH}_3\text{—}^{81}\text{Br}$ (at m/z 94 and m/z 96, respectively) should be of nearly equal intensity due to the relative natural abundances of ^{79}Br and ^{81}Br .
- (c) That the M^{\dagger} and $M^{\dagger} + 2$ peaks are of nearly equal intensity tells us that the compound contains bromine. $\text{C}_3\text{H}_7\text{Br}$ is therefore a likely molecular formula.

$\text{C}_3 = 36$	$\text{C}_3 = 36$
$\text{H}_7 = 7$	$\text{H}_7 = 7$
$^{79}\text{Br} = \underline{79}$	$^{81}\text{Br} = \underline{81}$
$m/z = 122$	$m/z = 124$

Example :

The actual atomic masses of the molecules are all different (though nominally they all have atomic mass of 32):

$$\text{O}_2 = 2(15.9949) = 31.9898$$

$$\text{N}_2\text{H}_4 = 2(14.0031) + 4(1.00783) = 32.0375$$

$$\text{CH}_4\text{O} = 12.00000 + 4(1.00783) + 15.9949 = 32.0262$$

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